Historic, Archive Document

Do not assume content reflects current scientific knowledge, policies, or practices.

Proceedings— Symposium on Ecology and Management of Riparian Shrub Communities

SHRUB RESEARCH CONSORTIUM

USDA Forest Service, Intermountain Research Station, Shrub Sciences Laboratory*, Provo, Utah, E. Durant McArthur (Chairman);

Brigham Young University*, Provo, Utah, Jerran T. Flinders;

USDA Agricultural Research Service, Mountain States Area*, Reno, Nevada, James A. Young;

Utah State University*, Logan, Frederick D. Provenza;

State of Utah, Department of Natural Resources, Division of Wildlife Resources*, Salt Lake City, David K. Mann;

University of California, Los Angeles, Evan M. Romney;

Colorado State University, Fort Collins, William K. Lauenroth;

University of Idaho, Moscow, Steven J. Brunsfeld;

University of Montana, Missoula, Don Bedunah;

Montana State University, Bozeman, Carl L. Wambolt;

University of Nevada-Reno, Paul T. Tueller;

University of Nevada, Las Vegas, Stanley D. Smith;

Oregon State University, Corvallis, Lee E. Eddleman;

New Mexico State University, Las Cruces, Max P. Dunford;

Texas A & M System, Texas Agricultural Experiment Station, San Angelo, Darrell N. Ueckert;

Texas Tech University, Lubbock, Ronald E. Sosebee;

USDA Agricultural Research Service, High Plains Grassland Research Station, Cheyenne, D. Terrance Booth;

USDA Agricultural Research Service, Jornada Experimental Range, Las Cruces, New Mexico, Jerry R. Barrow;

University of Utah, Salt Lake City, James R. Ehleringer;

Weber State University, Ogden, Utah, Cyrus M. McKell;

University of Wyoming, Laramie, Rollin H. Abernethy.

---

*Charter members

Proceedings—Symposium on Ecology and Management of Riparian Shrub Communities

Sun Valley, ID, May 29-31, 1991

Compilers:

WARREN P. CLARY, Project Leader, Forestry Sciences Laboratory, Intermountain Research Station, Boise, ID

E. DURANT McARTHUR, Project Leader, Shrub Sciences Laboratory, Intermountain Research Station, Provo, UT

DON BEDUNAH, Professor, School of Forestry, University of Montana, Missoula

CARL L. WAMBOLT, Professor, Department of Animal and Range Sciences, Montana State University, Bozeman

CONTENTS

INTRODUCTION: ECOLOGY AND MANAGEMENT OF RIPARIAN SHRUB COMMUNITIES

Warren P. Clary
E. Durant McArthur

This publication consists of papers presented at the seventh symposium in a series devoted to the biology and management of western wildland shrubs. The symposium focus was on riparian shrub communities and their habitats. Proceedings of the previous symposia have been published by the Intermountain Research Station (McArthur and others 1990; McArthur and Welch 1986; Provenza and others 1987; Tiedemann and Johnson 1983; Tiedemann and others 1984; Wallace and others 1989). The Shrub Research Consortium (SRC) (see inside front cover of the proceedings) sponsors this symposia series.

The timing of this riparian symposium was particularly appropriate because of current concerns about values and condition of riparian areas, how to rehabilitate riparian areas, and how to manage them for long-term benefits. Although riparian areas may constitute less than 1 percent of the Western United States landscape, their biologic and hydrologic importance is far out of proportion to their area. Riparian plant communities are typically composed of distinctive species and, compared to adjacent communities, often have denser populations and larger individuals. This creates an oasis effect producing ecosystems rich in bird and animal life (Szaro 1989). Riparian systems are so dynamic that the traditional climax and habitat-type concepts have been largely set aside and replaced with approaches such as riparian association and riparian complex (Campbell and Green 1968; Kovalchik 1987; Winward and Padgett 1989). As a further complication, the response of riparian areas to grazing stress is often quite different than might be expected from upland experience (Clary and Webster 1990; Skovlin 1984). Currently, the availability of rehabilitation plant materials and techniques is relatively limited. Little information was reported as recently as 1985 (Johnson and others 1985), but experience in rehabilitation is expanding rapidly (Abell 1989).

This symposium was held to acquaint individuals more familar with upland habitats with some of the current information on riparian areas. The symposium agenda consisted of a call to order by Durant McArthur, Chairman, SRC, a welcome by Carl Pence, Area Ranger, Sawtooth National Recreational Area (SNRA), and 45 technical presentations. Two field trips, a premeeting tour of unique *Artemisia* communities and an all-day midmeeting field trip through mountain meadow riparian ecosystems, provided the opportunity for meeting participants to examine specific plant communities and observe the effects of management. Forty-one papers and accounts of the field trips are included in this publication.

The papers are presented in five sections including one for field trips. Section 1 of the proceedings covers distribution and ecology of riparian shrubs. Here we learn of the environmental events often necessary for successional progress in riparian habitats. Several presenters describe the channel type, valley bottom conditions, and elevations necessary to support specific riparian shrub species and communities, thus improving our understanding of riparian site potential. We obtain new information from other papers on the depths of plant water withdrawal, response of riparian communities to drought and fire stresses, and clonal expansion. The concept of xeroriparian communities is also presented.

A first step in effective study or management of natural systems is to organize and classify the populations in question. Several papers in Section 2 present a background for understanding the composition and variability of riparian plant communities and habitats and, therefore, provide bases for classification. Classification of riparian areas will aid in understanding many aspects including the different responses to environmental stress. Ungulate grazing is the most widespread riparian stress in the Western United States. Information on different responses to grazing animals and grazing systems by riparian plants and plant communities, small wildlife populations, and soils is presented. Riparian politics is also described.

The multiple stresses of grazing in combination with recreation, road building, logging, mining, and flooding and sedimentation from deteriorated watersheds have contributed to the depletion of many riparian areas. The recovery of such areas is a priority action item for land management agencies. Readers of Section 3 will obtain information on the conditions required for natural establishment of various woody riparian plants. The selection of species, application of seed technology, and methodology for use of cuttings to artificially establish woody plants are also described.

A fourth section covers ecology and management of upland shrubs in the interest of the continuing goal of SRC to promote and publicize a broad spectrum of shrubland research and management. Response to moisture stress, geographic races and metabolism, soil interactions, insects and stress, seed dormancy, plant yields, and fire effects are among the subjects included.

Warren P. Clary is Project Leader and Supervisory Range Scientist (Boise Forestry Sciences Laboratory) and E. Durant McArthur is Project Leader and Chief Research Geneticist (Provo Shrub Sciences Laboratory), Intermountain Research Station, Forest Service, U.S. Department of Agriculture.

The field trip reports, Section 5, take the reader through two informative excursions. The Pre-Wildland Shrub Symposium Tour, en route to Sun Valley, focused primarily on upland shrub communities on basaltic soils, several of which have rather limited geographic distributions. The midmeeting field trip traversed the spectacular SNRA. Special emphasis was given to the relationship between domestic livestock grazing and riparian-stream conditions at several stops in these high-mountain meadows. General interest stops included the SNRA headquarters, scenic Redfish Lake, and the Sawtooth Fish Hatchery.

ACKNOWLEDGMENTS

REFERENCES

Abell, Dana L., tech. coord. 1989. Proceedings of the California riparian systems conference: protection, management, and restoration for the 1990's; 1988 September 22-24; Davis, CA. Gen. Tech. Rep. PSW-110. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 544 p.

Campbell, C. J.; Green, Win. 1968. Perpetual succession of stream-channel vegetation in a semiarid region. Journal of the Arizona Academy of Science. 5(2): 86-98.

Clary, Warren P.; Webster, Bert F. 1990. Riparian grazing guidelines for the Intermountain Region. Rangelands. 12(4): 209-212.

Johnson, R. Roy; Ziebell, Charles D.; Patton, David R.; Ffolliott, Peter F.; Hamre, R. H., tech. coords. 1985. Riparian ecosystems and their management: reconciling conflicting uses: First North American riparian conference; 1985 April 16-18; Tucson, AZ. Gen. Tech. Rep. RM-120. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 523 p.

Kovalchik, Bernard L. 1987. Riparian zone associations: Deschutes, Ochoco, Fremont, and Winema National Forests. R6 ECOL TP-279-87. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 171 p.

McArthur, E. Durant; Romney, Evan M.; Smith, Stanley D.; Tueller, Paul T., compilers. 1990. Proceedings—symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 351 p.

McArthur, E. Durant; Welch, Bruce L., compilers. 1986. Proceedings—symposium on the biology of *Artemisia* and *Chrysothamnus*; 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 398 p.

Provenza, Frederick D.; Flinders, Jerran T.; McArthur, E. Durant, compilers. 1987. Proceedings—symposium on plant-herbivore interactions; 1985 August 7-9; Snowbird, UT. Gen. Tech. Rep. INT-222. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 179 p.

Skovlin, Jon M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Developing strategies for rangeland management. Boulder, CO: Westview Press: 1001-1103.

Szaro, Robert C. 1989. Riparian forest and scrubland community types of Arizona and New Mexico. Desert Plants. [Special Issue] 9(3-4): 70-138.

Tiedemann, Arthur R.; Johnson, Kendall L., compilers. 1983. Proceedings—research and management of bitterbrush and cliffrose in Western North America; 1982 April 13-15; Salt Lake City, UT. Gen. Tech. Rep. INT-152. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 279 p.

Tiedemann, Arthur R.; McArthur, E. Durant; Stutz, Howard C.; Stevens, Richard; Johnson, Kendall L., compilers. 1984. Proceedings—symposium on the biology of *Atriplex* and related chenopods; 1983 May 2-6; Provo, UT. Gen. Tech. Rep. INT-172. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 309 p.

Wallace, Arthur; McArthur, E. Durant; Haferkamp, Marshall R., compilers. 1989. Proceedings—symposium on shrub ecophysiology and biotechnology; 1987 June 30-July 2; Logan, UT. Gen. Tech. Rep. INT-256. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 183 p.

Winward, Alma H.; Padgett, Wayne G. 1989. Special considerations when classifying riparian areas. In: Ferguson, Dennis E.; Morgan, Penelope; Johnson, Frederic D., compilers. Proceedings—land classifications based on vegetation: applications for resource management; 1987 November 17-19; Moscow, ID. Gen. Tech. Rep. INT-257. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 176-179.

Section 1—Distribution and Ecology of Riparian Shrubs

MULTIVARIATE ANALYSIS OF WOODY PLANT SUCCESSION ON THE TANANA RIVER IN INTERIOR ALASKA

Phyllis C. Adams
Leslie A. Viereck

ABSTRACT

Woody plant succession on the Tanana River floodplain was analyzed using multivariate techniques. Numerical classification results were consistent with the well-described vegetation chronosequence. Variation in community composition along an environmental gradient was high in intermediate stages, but decreased in later successional stages. Directionality along the gradient varied less late in the chronosequence. These analyses support the contention that physical, fluvial controls of early succession are dampened by biotic factors in later successional stages.

INTRODUCTION

Stochastic environmental events play a major role in establishing the pattern of primary succession on the floodplain of the Tanana River in interior Alaska. Fluvial processes initiate this pattern through the deposition of silt, creating bars suitable for plant colonization. Seasonal changes in river level influence the establishment and growth of plant species in early successional stages through deposition of sand and silt, inundation and burial of seedlings, and control of soil moisture. After establishment of seedlings, additional deposition of silt along with accumulation of litter from the developing vegetation results in terraces, which increase in elevation with time and distance from the river. The formation of a thick, insulating organic layer on older terraces leads to the development of permafrost. These processes result in a series of successional stages on relatively flat topography, and have been summarized in numerous studies of successional processes (Van Cleve and Viereck 1981; Van Cleve and others 1980; Viereck 1970; Walker 1985; Walker and others 1986).

Some of these studies (Walker and others 1986) reject the traditional Clementsian view of succession (Clements 1936), concluding that the successional sequence is adequately explained by the stochastic events related to flooding and seed dispersal and by the life history traits of the dominant species. Other studies (Van Cleve and others 1980; Viereck 1970) have concluded that facilitative interactions among species are at least partially responsible for driving successional changes on the Tanana River floodplain.

These facilitative interactions include the model of Connell and Slayter (1977), whereby early successional stages modify the environment, creating optimum conditions for later successional species, supporting Clements' (1936) classical succession concepts. These concepts are further supported by Egler's (1954) "relay floristics" hypothesis in which species associations replace each other as groups in a temporal sequence. An alternative model presented by Egler (1954), the "initial floristic composition" model, assumes many of the final or climax species are present as seeds or live roots from the start of the successional sequence. Drury and Nisbet (1973) contended that the presence of later successional species in early stages of succession throws doubt on the importance of the early successional stages in modifying the environment, and thus is in opposition to the facilitative model of Connell and Slayter (1977).

Margalef (1968) proposed that fluctuations in species composition in early successional stages should be dampened by the emergent properties of the biotic community, leading to convergence. In support of this hypothesis, Van Cleve and Viereck (1981) concluded that early successional sequences on the Tanana River floodplain are controlled primarily by physical processes such as flooding, siltation, and erosion, while the later stages of succession reflect the dominance of biological control. This implies that vegetation composition in early successional stages is highly stochastic and nondirectional, while the directionality of later stages is more deterministic.

The objective of this study was to investigate the patterns of woody plant succession on the Tanana River floodplain using multivariate analytical techniques. Sites were grouped into cover types by TWINSPAN classification. Variability in woody plant species associations among sites was assessed through ordination techniques, and the variability within cover types was examined by means of cover type overlays of the sites in ordination space. The rate and direction of successional patterns, the convergence of species associations, and the degree to which succession is controlled by physical processes were examined.

STUDY AREA

The study area is located along a portion of the Tanana River in and adjacent to the Bonanza Creek Experimental Forest (BCEF) near Fairbanks, AK. The Tanana is a large, glacially fed river that originates in the Alaska Range and flows through the boreal forest in interior Alaska. A braided,

meandering river along much of its length, the broad flood-plain of the Tanana is constantly being reshaped by active erosion and deposition (Collins 1990).

The climate of the area is strongly continental and is characterized by temperature extremes from –50 to +35 °C. The average annual precipitation is 269 mm. Most precipitation falls as rain in the summer months with one-third falling as snow in accumulations averaging 75 cm. The mean annual temperature of –3.3 °C at Fairbanks causes the formation of permanently frozen soils (permafrost), resulting in poorly drained sites where insulating vegetation has developed. The Tanana River basin is located entirely within the discontinous permafrost zone (Ferrians 1965).

The vegetation succession pattern on the floodplain of the Tanana River is well described (Van Cleve and Viereck 1981; Viereck 1970; Viereck 1989). The successional sequence begins with alluvial deposition on the inside of river meanders, providing conditions favorable for the establishment of willows (*Salix* spp.) and thinleaf alders (*Alnus tenuifolia* Nutt.). Balsam poplars (*Populus balsamifera* L.) also become established on these early sites, but are slower growing. After the river terraces have been built to sufficient height to prevent annual river inundation, white spruce (*Picea glauca* [Moench] Voss) seedlings persist and eventually overtop the balsam poplars. With development of permafrost, black spruce (*Picea mariana* [Mill.] B.S.P.) and bogs replace white spruce stands.

DATA COLLECTION

Permanent vegetation plots were established in the different successional stages along the Tanana River. Cover of low shrubs, herbs, mosses, and lichens was measured in 1-m² plots; shrub cover and density were measured in 4-m² plots. At each site trees were measured and tagged within a 500- to 3,000-m² area, depending on the density of the stand. Approximate age of the dominant species was determined. Plots have been remeasured at approximately 5-year intervals; some of these plots were established as early as 1966.

In addition, other stand attributes such as aboveground biomass, terrace height above the river, and soil texture have been obtained for many of these sites. In this study only data from the 19 tree and shrub species occurring at these sites (table 1) were used, and the stands chosen for analysis do not include the later successional black spruce stands or bogs.

DATA ANALYSIS

Stand data for the woody vegetation were summarized and mean stand values for percent canopy cover were used in data analyses. TWINSPAN, the polythetic, divisive classification (Hill 1979a; program CEP-41 in Cornell Ecology Programs Series) was used to classify stands into compositional groups on the basis of species cover percentages. TWINSPAN arranges the sites into distinct groups by appropriate divisions of sites arranged along the first axis of a refined reciprocal averaging (RA) ordination. The program also produces a grouping of species based on floristic similarities among sites. The TWINSPAN program was run using the default options.

Table 1—Tree and shrub species included in this study and abbreviations used

Species	Abbreviations
Alnus crispa	Alcr
Alnus tenuifolia	Alte
Betula glandulosa	Begl
Betula papyrifera	Bepa
Cornus stolonifera	Cost
Picea glauca	Pigl
Populus balsamifera	Poba
Populus tremuloides	Potr
Rosa acicularis	Roac
Rubus idaeus	Ruid
Salix alaxensis	Saal
Salix arbusculoides	Saar
Salix bebbiana	Sabe
Salix brachycarpa	Sabr
Salix interior	Sain
Salix lasiandra	Sala
Salix monticola	Samo
Salix novae-angliae	Sano
Viburnum edule	Vied

Ordination techniques summarize data into low-dimensional spaces, which are easier to examine for patterns (Gauch 1982). In this study ordinations were performed on mean cover of woody species in each stand to display the relationship in vegetation variability among the stands.

DECORANA, a detrended correspondence analysis (DCA) method (Hill 1979b; CEP-40 in Cornell Ecology Programs Series) was used to produce ordinations of species and sites. DCA was designed to suppress the "arch effect" that frequently characterizes other ordination techniques (Parker 1988), allowing DCA to produce superior results compared to other available ordination techniques. In addition, DECORANA rescales distances along the axes allowing easier interpretation in terms of ecological distance. Although DCA is presently the most popular ordination method, it has been criticized because the detrending and rescaling are arbitrary (Minchin 1987), and Gauch (1982) recommends using more than one technique when available.

A principal components analysis (PCA), the oldest and most straightforward of the indirect ordination methods (Digby and Kempton 1987), was performed using SAS PROC PRINCOMP (SAS Institute 1987). The variance-covariance matrix, rather than the correlation matrix, was used for the PCA because the absolute abundance of a species within a plant assemblage (as represented by cover values) can be important in determining the degree of interaction among species (Moloney 1989).

Stand ages were correlated with the DCA and PCA scores using SAS PROC REG (SAS Institute 1987). Other physical site characteristic data were not available for all the sites at this time, and other correlations of interest were not performed.

Directionality of succession can be examined by arranging ordination scores along a gradient. Trajectories of four sites measured at approximately 5-year intervals were plotted on the DCA ordination space in order to examine

the directionality of these sites along the first and second DCA axes.

CLASSIFICATION RESULTS

The TWINSPAN classification of the 66 stands produced eight stand groups (fig. 1), which separate along a classic successional sequence. Stand group 1 includes the earliest successional stage, Stage II, in the sequence described by Viereck (1989). These stands are characterized by scattered willow and herb species on bare, recently deposited alluvium. The major shrub and tree species include sandbar willow (*Salix interior* Rowlee), feltleaf willow (*Salix alaxensis* [Anderss.] Cov.), tall blueberry willow (*Salix novae-angliae* Anderss.), and balsam poplar. Thinleaf alder and white spruce are present in small amounts.

Stand group 2 consists of the open, young willow stands of Stage III (Viereck 1989), with willows from 0.5 to 1.5 m in height. Tree and shrub species represented in this group include sandbar willow, Pacific willow (*Salix lasiandra* Benth.), feltleaf willow, barren-ground willow (*Salix brachycarpa* Nutt.), balsam poplar, and thinleaf alder. White spruce seedlings are also present in most of these stands.

Stand groups 3 and 4 include Stages IV and V of the successional sequence (Viereck 1989). Group 3 is differentiated

from group 4 in the TWINSPAN analysis by the presence of tall blueberry willow. These stands include closed alder and willow shrubs with balsam poplar stems reaching through the shrub canopy.

Stand groups 5 through 8 represent the closed canopy stands. These stands are differentiated by increasing cover of rose (*Rosa acicularis* Lindl.). Stand groups 5 through 7 are dominated by balsam poplar with high bush cranberry (*Viburnum edule* [Michx.] Raf.) in the understory reaching maximum cover in group 7. These groups include Stages VI-VII of the successional sequence described by Viereck (1989). Stand group 8 includes the mature even-aged white spruce stands (Stage VIII).

Five species associations were recognized by the TWINSPAN analysis. The distribution across the eight stand groups and frequency of occurrence within each stand group of the most abundant species in each species group are shown in figure 2. Species groups A and B are representative of the early successional stages of stand groups 1 through 4. Species group C, with thinleaf alder and balsam poplar, is represented in all stand groups. However, the presence of balsam poplar is infrequent in stand group 8. Species group D includes white spruce, which is present in all stand groups, as well as paper birch (*Betula papyrifera* Marsh.) and raspberry (*Rubus idaeus* L.), which are found

Figure 1—TWINSPAN dendrogram of 66 stands on the Tanana River floodplain based on 19 tree and shrub species (table 1). Indicator species names are abbreviated to the first two letters of the genus and species names (table 1).

Figure 2—Frequency distribution of the primary species of the TWINSPAN species groups across the stand groups from figure 1.

in the later successional stages of stand groups 7 and 8. Species group E, with three late successional species, is heavily represented in the later stages of stand groups 5-8.

ORDINATIONS

The arrangement of the 66 stands on the DCA species ordination and their classification into TWINSPAN stand groups are presented in figure 3. The first three DCA axes explain 95 percent of the variance in species composition of the stands, with 65 percent explained by the first axis alone. All three axes represent gradients, although it is not clear what environmental factors are being ordered. Stand group 8 is distinct from the remaining classification groups. Stand

group 1 falls completely within group 2 and adds little to the variability in species abundance. The intermediate successional stages overlap considerably in the ordination space. Although included in the ordinations, Stand 130 is an anomaly and was not placed in the TWINSPAN classification groups.

Similarily, 95 percent of the variance in species composition of the 66 stands is explained by the first three principal components axes of the vegetation PCA (fig. 4). The first PC axis alone explains 62 percent of the variance. There is little overlap of the mature white spruce and the willow groups with the intermediate groups in the PCA ordination space. The third PC axis with 16 percent of the variance distinguishes stand groups 7 and 8 from the remaining stand groups and is correlated with stand age ($r^2 = 0.61$).
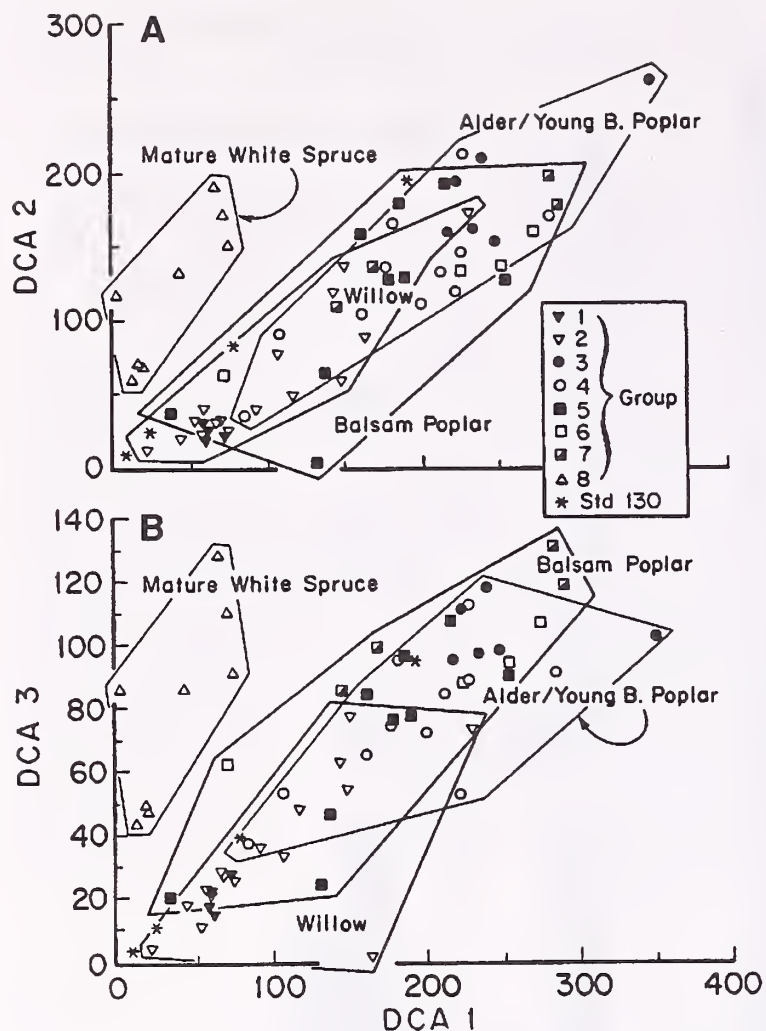
Figure 3—DCA ordination of 66 stands based on 19 tree and shrub species (table 1). TWINSPAN stand groups are indicated by symbols and grouped into vegetation types by polygons.
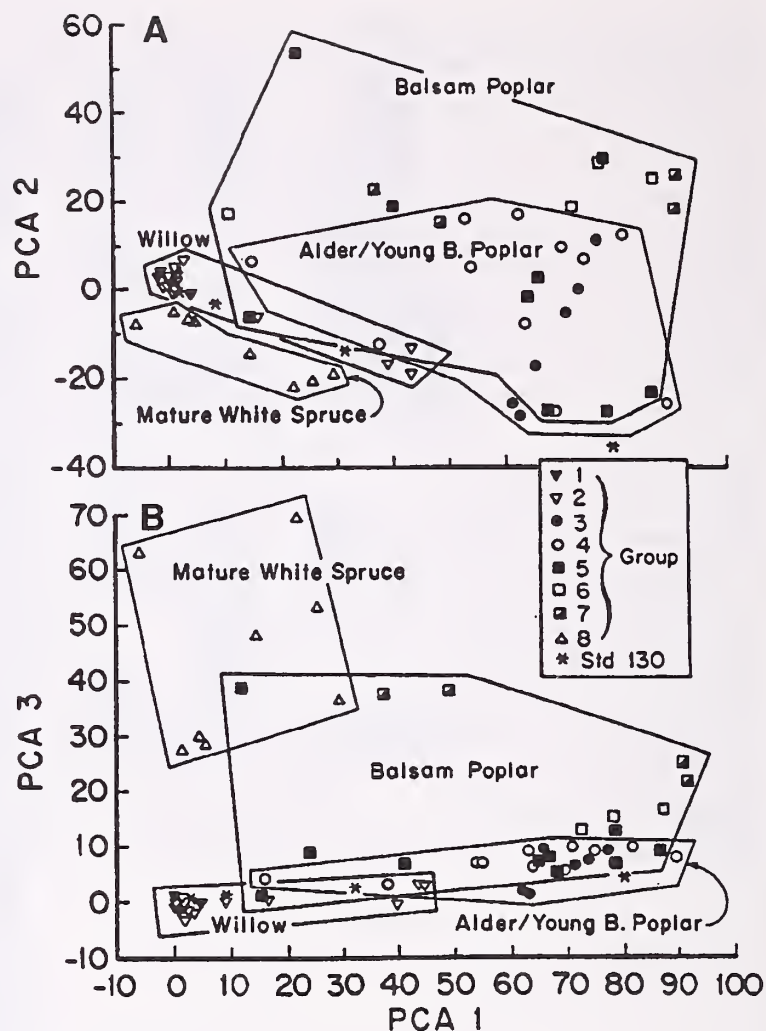
Figure 4—PCA ordination of 66 stands based on 19 tree and shrub species (table 1). TWINSPAN stand groups are indicated by symbols and grouped into vegetation types by polygons.

Trajectories of four sites measured at approximately 5-year intervals are shown in figure 5. A reversal in direction of the trajectories along the ordination axes occurred at all four sites, although the effect was least at the mature white spruce site.

DISCUSSION

The TWINSPAN classification of woody species on the Tanana River floodplain is consistent with the classification described by Viereck (1989), numerically confirming the initial subjective classification along this successional gradient. Subsequent measurement of vegetative cover at many of these sites resulted in their placement in later successional TWINSPAN groups, supporting the previously described successional pathway. The major division of the stands occurs with the replacement of the early floodplain willows by later successional shrubs, supporting Egler's (1954) relay floristic model. Figure 2 illustrates this replacement; species groups A and B dominate the early successional sites, but are replaced by later successional species
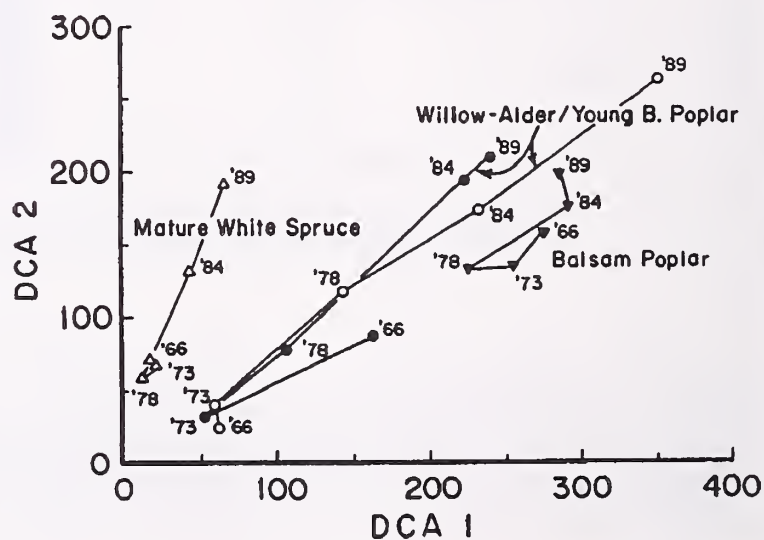
Figure 5—Trajectory of four successional sites in the space determined by the first two DCA axes. Numbers represent years plots were measured. Successional stages are indicated for each site.

of groups D and E in the mature forest stands. Some species do, however, follow the initial floristic model. Thinleaf alder and white spruce appear in the earliest stages and are present throughout the successional sequence examined here. Balsam poplar, although abundant in early stages of succession, occurs only rarely in the mature white spruce stage. Thinleaf alder and white spruce would also be replaced by late successional species in a longer successional sequence that included the black spruce stages.

The major TWINSPAN division of the stands is not evident in the ordination analyses where stand groups 3 through 7 are indistinct, suggesting little differentiation among these groups in ecological space. The axis scores of the willows used by TWINSPAN as indicator species in the first division are high, however, confirming their importance in ordering stands.

Both the DCA and PCA ordinations of the tree and shrub species across several successional stages reveal distinct environmental gradients. With the exception of the third PCA axis, which is related in part to stand age, the identity of the gradients is unclear and requires further study. Additional correlation analyses to examine the relationships between the species associations and background abiotic factors may aid in the identification of these gradients, thus suggesting physical factors influencing the rate and direction of the successional sequence.

Successional convergence, a trend toward increased uniformity in species composition resulting from interactions among dominant species and their alteration of the physical environment (Clements 1916), can be measured in terms of species turnover along gradients (Whittaker 1972). DECORANA directly calculates species change along gradients in units of standard deviations of species abundance (Christensen and Peet 1984). The TWINSPAN stand groups 3 and 4 have the highest variability in DCA scores along the first axis (fig. 3A, B). This indicates that the maximum species turnover occurs in the intermediate stages of the successional sequence. Stand groups 1 and 8, in contrast, have the lowest variability in DCA scores along the first axis, indicating that very little species variability occurs in the earliest stage or in the mature white spruce stage. This might suggest that convergence is occurring in the earliest successional stages as well as in the mature white spruce stands, while the intermediate stages are divergent. The low variability of the early successional stage may, however, be a function of physical controls limiting species establishment. In a study of species establishment on bars of the Tanana River, Krasny (1986) found no obvious environmental gradient in DCA ordinations of early successional species. She attributed this to the fact that a single river bar species may grow under a range of environmental conditions. These results support Margalef's (1968) hypothesis that interspecific interactions are the controlling forces shaping community structure in later succession, outweighing the random fluctuations imposed on early successional stages.

Directional change in community species composition is also a measure of the extent of biotic dampening of the random fluctuations (Facelli and D'Angela 1990). Directionality was examined by arranging ordination scores along a gradient (fig. 5). The reversal in direction of the trajectories along the ordination axes occurred at all four sites, and

may be attributed to physical changes imposed by a major flood in 1967. From the reversal, the intermediate successional sites appear to have required up to 10 years to recover, while the mature white spruce site was less affected and recovered more quickly. This is consistent with Margalef's (1968) hypothesis that earlier stages are affected by random fluctuations (flooding in this case) to a greater extent than later stages.

The effects of major floods on the analyses suggest that the random fluctuations in flooding and alluvial deposition are responsible for the changes in species composition, and thus lack of directionality, in these earlier-to-intermediate stages. Examination of the Moose Creek Bluff site (LV130), a site where the usual species replacements have not occurred, supports this contention. This site is unique in its location upriver from Fairbanks, and is isolated from the dynamics of the physical controls of the river. The nature of the river changes at Fairbanks from a braided river with typically unstable bars and multiple channels upstream to a pattern of several meandering main channels with stable vegetated islands downstream of Fairbanks (Collins 1990). In addition, the dynamic nature of the river has been arrested in the vicinity of Moose Creek Bluff by flood control projects. Neither balsam poplar nor white spruce seedlings became established at this site, and the thinleaf alders are being replaced by bluejoint (*Calamagrostis canadensis* [Michx.] Beauv.), usually a minor species on the floodplain, resulting in an alternative successional sequence.

This alternative successional path in the absence of stochastic fluvial processes is consistent with the argument that river dynamics play a major role in species replacement in early stages of succession on the Tanana River floodplain. Other analyses reported in this paper also support the contention that the early successional sequence on the Tanana River floodplain is controlled primarily by physical processes associated with river dynamics, and that these fluctuations are dampened by biotic interactions in later successional stages.

ACKNOWLEDGMENTS

REFERENCES

Christensen, N. L.; Peet, R. K. 1984. Convergence during secondary forest succession. Journal of Ecology. 72: 25-36.

Clements, F. E. 1916. Plant succession: an analysis of the development of vegetation. Publ. 242. Washington, DC: Carnegie Institute. 512 p.

Clements, F. E. 1936. Nature and structure of the climax. Journal of Ecology. 24: 252-284.

Collins, Charles M. 1990. Morphometric analyses of recent channel changes on the Tanana River in the vicinity of

Fairbanks, Alaska. CRREL Report 90-4. Hanover, NH: U.S. Army Corps of Engineers, Cold Regions Research & Engineering Laboratory. 48 p.

Connell, J. H.; Slatyer, R. O. 1977. Mechanisms of succession in natural communities and their role in community stability and organization. American Naturalist. 111: 1119-1144.

Digby, P. G. N.; Kempton, R. A. 1987. Multivariate analysis of ecological communities. New York: Chapman and Hall. 206 p.

Drury, W. H.; Nisbet, I. C. T. 1973. Succession. Journal of the Arnold Arboretum. 54: 331-368.

Egler, F. E. 1954. Vegetation science concepts. 1. Initial floristic composition—a factor in old-field vegetation development. Vegetatio. 4: 412-417.

Facelli, Jose M.; D'Angela, Evelina. 1990. Directionality, convergence, and rate of change during early succession in the Inland Pampa, Argentina. Journal of Vegetation Science. 1: 255-260.

Ferrians, O. J., Jr. 1965. Permafrost map of Alaska. Misc. Geol. Invest. Map 1-445. Washington, DC: U.S. Geological Survey. 1 sheet.

Gauch, Hugh G., Jr. 1982. Multivariate analysis in community ecology. Cambridge: Cambridge University Press. 298 p.

Hill, M. O. 1979a. TWINSPAN—a FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Ithaca, NY: Cornell University, Ecology and Systematics. 90 p.

Hill, M. O. 1979b. DECORANA—a FORTRAN program for detrended correspondence analysis and reciprocal averaging. Ithaca, NY: Cornell University, Ecology and Systematics. 52 p.

Krasny, Marianne Elizabeth. 1986. Establishment of four Salicaceae species on river bars along the Tanana River, Alaska. Seattle, WA: University of Washington. 152 p. Dissertation.

Margalef, R. 1968. Perspectives in ecological theory. Chicago: University of Chicago Press. 111 p.

Minchin, P. R. 1987. An evaluation of the relative robustness of techniques for ecological ordination. Vegetatio. 69: 89-107.

Moloney, Kirk A. 1989. The local distribution of a perennial bunchgrass: biotic or abiotic control? Vegetatio. 80: 47-61.

Parker, Kathleen C. 1988. Environmental relationships and vegetation associates of columnar cacti in the northern Sonoran Desert. Vegetatio. 78: 125-140.

SAS Institute. 1987. SAS user's guide, statistics. Cary, NC: SAS Institute.

Van Cleve, K.; Dyrness, T.; Viereck, L. A. 1980. Nutrient cycling in interior Alaska flood plains and its relationship to regeneration and subsequent forest development. In: Murray, M.; VanVeldhuizen, R. M., eds. Forest regeneration at high latitudes, the proceedings of an international workshop. 1979 November 15-16; Fairbanks, AK; Gen. Tech. Rep. PNW-107. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 11-18.

Van Cleve, K.; Viereck, L. A. 1981. Forest succession in relation to nutrient cycling in the boreal forest of Alaska. In: West, D.; Shugart, H.; Botkin, D., eds. Forest succession: concepts and application. New York: Springer-Verlag: 185-211.

Viereck, L. A. 1970. Forest succession and soil development adjacent to the Chena River in interior Alaska. Arctic and Alpine Research. 2: 1-26.

Viereck, Leslie A. 1989. Flood-plain succession and vegetation classification in interior Alaska. In: Ferguson, Dennis E.; Morgan, Penelope; Johnson, Frederic D., compilers. Proceedings—land classifications based on vegetation: applications for resource management; 1989 November 17-19; Moscow, ID. Gen. Tech. Rep. INT-257. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 197-203.

Walker, Lawrence Reddeford. 1985. The processes controlling primary succession on an Alaskan flood plain. Fairbanks, AK: University of Alaska Fairbanks. 185 p. Dissertation.

Walker, Lawrence R.; Zasada, John C.; Chapin, F. Stuart, III. 1986. The role of life history processes in primary succession on an Alaskan floodplain. Ecology. 67(5): 1243-1253.

Whittaker, R. H. 1972. Evolution and measurement of species diversity. Taxon. 21: 213-251.

245

DISTRIBUTION OF WILLOWS ON FOREST LANDS OF NEVADA AND EASTERN CALIFORNIA

M. E. Manning
W. G. Padgett

ABSTRACT

Distributions and habitat characteristics of 14 common willows, including one undescribed variety of Salix lutea *Nutt., are described for the Toiyabe and Humboldt National Forests of Nevada and eastern California. Some species have restricted geographic distribution while others occur throughout the study area. Locally, species segregate by elevation and site characteristics. This information can assist the land manager in understanding site potential, as well as species selection for revegetation and rehabilitation projects in the study area.*

INTRODUCTION

Willow identification in Nevada, particularly central Nevada, is difficult because no current regional flora for *Salix* spp. exist. In addition, high phenotypic variability among disjunct willow populations in the study area occasionally makes positive identification difficult. Various low- and tall-growing willows, some common throughout the Western United States, occur in the study area. Fourteen species are discussed in this report (table 1), including one undescribed willow that the authors believe to be a nonglaucous form of *Salix lutea* Nutt.

The study area included the Toiyabe and Humboldt National Forests of Nevada and eastern California (fig. 1). Data were collected for the classification of riparian plant communities in the study area (Manning and Padgett in review) and are not intended to represent an exhaustive search for willow distribution in the study area.

Floristic sections described by Manning and Padgett (in review) are shown in figure 2. They are similar to those described by Cronquist and others (1972) with some modifications based on distribution of some dominant upland species as well as occurrence of various riparian species. The Toiyabe and Humboldt National Forests occupy portions of at least eight floristic sections, including the Eastern Sierra Nevada, Reno, Central Great Basin, Tonopah, Lake, Northeastern Great Basin, Calcareous Mountains, and Mojave Floristic Sections.

"Low" willows, or those that typically grow to less than 6 ft at maturity, typically occur in cold, subalpine settings.

Salix orestera C. K. Scheid., *S. wolfii* Bebb, *S. planifolia* Pursh, *S. eastwoodiae* Cockerell, and *S. commutata* Bebb, are among the low willows occurring in the study area. Of these, *Salix commutata* was sampled infrequently and will not be discussed in this report.

"Tall" willows are generally 6 ft or greater at maturity and occur from sea level to upper montane zones, rarely occurring in subalpine settings. Among the tall species are *Salix lasiolepis* Benth., *S. lasiandra* Benth., *S. exigua* Nutt., *S. lutea, S. scouleriana* Barratt, *S. boothii* Dorn, *S. geyeriana* Anderss., *S. bebbiana* Sarg., *S. lemmonii* Bebb, and *S. drummondiana* Barratt. Because *Salix scouleriana* is typically an upland species, data collected for our study of riparian plant communities did not adequately assess its distribution. We have, therefore, excluded this species from further discussion.

One tall willow common in the Toiyabe, Toquima, Shoshone, and Monitor Ranges of the Central Great Basin Floristic Section has not been previously described, or may be inadequately described in available flora. This willow keys to *Salix boothii* using "A Utah Flora" (Welsh and others 1987), to *Salix pseudocordata* (Anderss.) Rydb. using "A California Flora" (Munz 1973), and to *S. myrtillifolia* Anderss. using "Flora of the Pacific Northwest" (Hitchcock and Cronquist 1976). Dorn (1975, 1988) noted

Table 1—Common "low" and "tall" willows of the Humboldt and Toiyabe National Forests of Nevada and eastern California

Low willows[1]

Salix commutata Bebb
Salix eastwoodiae Cockerell
Salix orestera C. K. Scheid.
Salix planifolia Pursh
Salix wolfii Bebb

Tall willows[2]

Salix bebbiana Sarg.
Salix boothii Dorn
Salix drummondiana Barratt
Salix exigua Nutt.
Salix geyeriana Anderss.
Salix lasiolepis Benth.
Salix lasiandra Benth.
Salix lemmonii Bebb
Salix lutea Nutt.
Salix lutea undescribed, nonglaucous form

[1]Willow height typically less than 6 ft at maturity.
[2]Willow height typically greater than 6 ft at maturity.

that *Salix pseudocordata* is not valid under the rules of nomenclature, and the name *Salix myrtillifolia*, a species of Alaska and Canada, has been misapplied to specimens of *S. boothii* in more southern latitudes. Central Nevada specimens are morphologically distinct from specimens of *Salix boothii* in northeastern Nevada as well as those observed in Utah, eastern Idaho, and western Wyoming. Individuals from central Nevada typically have more elliptic-shaped leaves, grayish-white bark, and highly divaricate branching. In addition, while capsule stipes are often within the range of length reported for *Salix boothii*, they may be longer and more similar to those of *S. lutea* (a similar species with glaucescence on lower leaf surfaces). Brunsfeld (1991), coauthor of "Field Guide to the Willows of East-Central Idaho" (Brunsfeld and Johnson 1985), indicated that there are nonglaucous forms of *Salix lutea; Salix monochroma* Ball is one such species and, while our specimens are similar to *Salix monochroma*, they do not have the thin leaves characteristic of this species.

Samples of the central Nevada specimens were sent to Dr. George Argus, willow taxonomist at the National Museum of Natural Sciences in Ottawa, ON, for his determination. Dr. Argus determined that they were probably a nonglaucous form of *Salix lutea*, based on vegetative characteristics (Argus 1989). He noted, however, that perhaps this is something other than *Salix lutea* and additional examination will be necessary to properly identify this species. For this report we will refer to this species as the "nonglaucous form of *Salix lutea*."

Specimens of the glaucous form of *Salix lutea* from central Nevada are also somewhat distinct from those occurring elsewhere in the study area as well as in eastern Idaho, Wyoming, and Utah. Leaf shape is more or less elliptic (rather than the common lanceolate shape), stipules are much less pronounced, and branching patterns (like those of the nonglaucous form) are much more divaricate in the central Nevada specimens. In his treatment of section *Cordatae* for North America, Dorn (1975) identified a *Salix lutea* complex rather than distinguishing individual species.
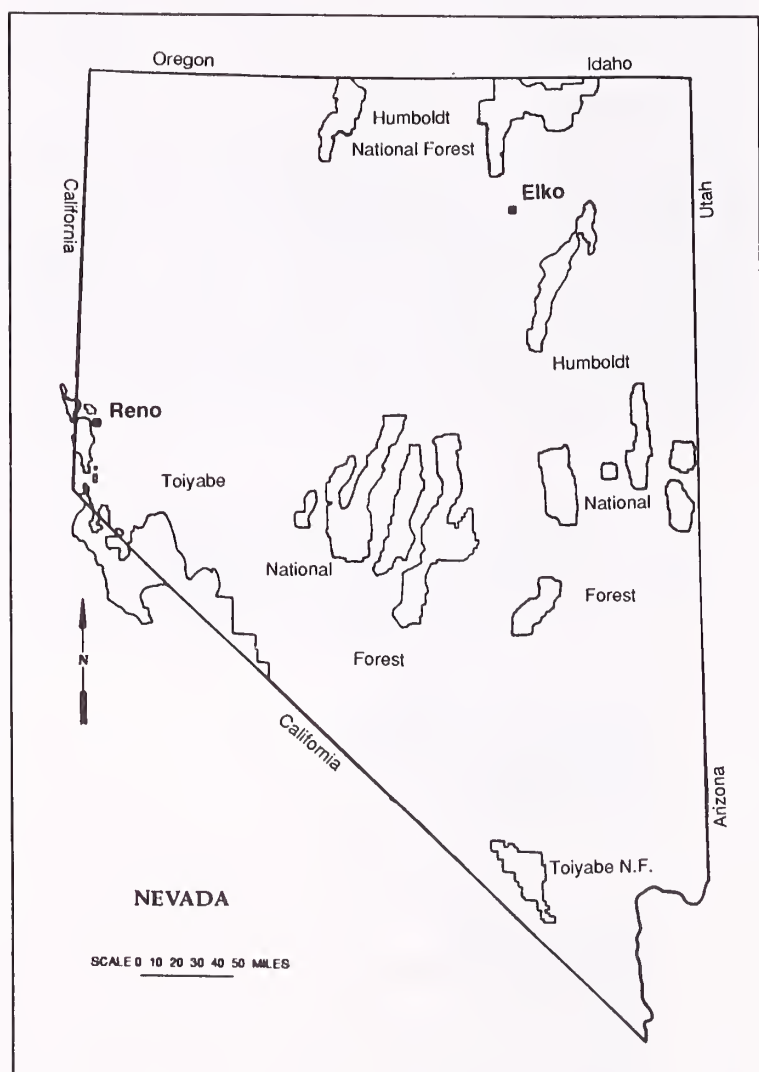

Figure 1—Toiyabe and Humboldt National Forests of Nevada and eastern California.
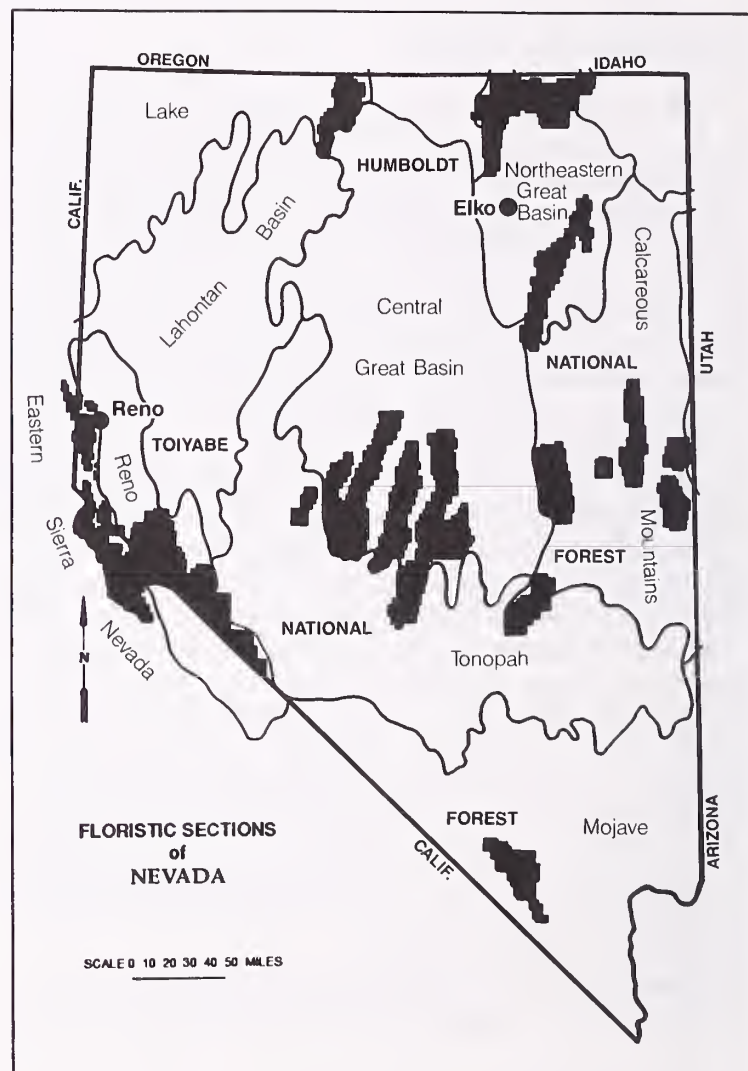

Figure 2—Floristic sections of the study area (Manning and Padgett in review) including the Eastern Sierra Nevada, Reno, Central Great Basin, Tonopah, Lake, Northeastern Great Basin, Calcareous Mountains, and Mojave Floristic Sections.

12

METHODS

Data for this report are not exhaustive and represent species distributions based on sampling for the classification of riparian plant communities in the Humboldt and Toiyabe National Forests of Nevada and eastern California (Manning and Padgett in review). A total of 820 communities were sampled for this report; of these communities, over half had willows present. Data are presented for 14 of the most common native willows within the study area.

Site data collected for each community included elevation, landscape position, valley bottom width (toeslope to toeslope), valley bottom gradient, and stream type (Rosgen 1985). Valley bottom width and gradient classes, modified from USDA (1978), are included in table 2. Soils were classified to the subgroup or family level.

Elevation ranges were calculated using all occurrences of a willow species. Site characteristics, however, are summarized only for communities where individual species had at least 25 percent canopy cover. The authors felt that a species' preference for site characteristics would be better expressed where that species either dominated or codominated the plant community.

RESULTS

The descriptions given here reflect typical site characteristics; exceptions to these may be mentioned briefly.

Salix bebbiana was sampled in the Central Great Basin (Toiyabe Range), Northeastern Great Basin (Independence and Ruby Mountains), and Calcareous Mountains (Schell Creek and White Pine Ranges) Floristic Sections. Elevations on National Forest lands ranged from 5,650 ft to over 8,500 ft, with higher elevations in the Calcareous Mountains Floristic Section. Valley bottom width ranged from narrow to moderate and valley bottom gradient was low to moderate. Communities were typically on benches adjacent to streams classified as A types, or on seeps (in the Schell Creek Mountains). Soils were Xerolls and Borolls, with some Aquolls, some with thick mollic epipedons. Family particle size classes varied; several were skeletal. Shallow water tables (within 40 inches) were encountered on several sampled sites.

Salix boothii was sampled in all but the Central Great Basin and Mojave Floristic Sections; in the Central Great Basin Floristic Section it is replaced by the nonglaucous form of *S. lutea*. Elevations on National Forest lands ranged from 5,750 ft in the Northeastern Great Basin Floristic Section to over 9,000 ft in the Reno Floristic Section. Valley bottom widths typically ranged from narrow to moderate, although some were broad and very broad. Valley bottom gradient was typically low or moderate. Most communities occupied benches adjacent to B and A channels, although a few were on seeps. Soils were mostly Mollisols (Borolls, Xerolls, or Aquolls) with thick mollic epipedons. Fluvents, Ochrepts, and Borohemists were also sampled. Family particle size classes varied, ranging from clay-loamy to sandy-skeletal. Several shallow water tables were encountered.

Table 2—Valley bottom characteristics as modified from USDA (1978)

Shape	Width
U	Very narrow (<10 yd)
V	Narrow (10-30 yd)
Trough	Moderate (30-100 yd)
Flat	Broad (100-300 yd)
Box	Very broad (>300 yd)
Gradient	**Side slope gradient**
Very low (<2 percent)	Low (<30 percent)
Low (2-3 percent)	Moderate (30-60 percent)
Moderate (4-5 percent)	Steep (>60 percent)
High (6-8 percent)	
Very high (>8 percent)	

Salix drummondiana, although uncommon, was either sampled or noted in the Eastern Sierra Nevada (Sierra Nevada), Lake (Santa Rosa Range), Central Great Basin (Toiyabe Range), and Northeastern Great Basin (Elk and Ruby Mountains) Floristic Sections. Elevations on National Forest lands ranged from 6,700 ft in the Northeastern Great Basin to over 9,600 ft in the Central Great Basin Floristic Section. Valley bottom width varied from narrow to broad; gradient varied from very low to very high. Communities of the Toiyabe Range were on steep, side-slope seeps; other communities were on well-aerated, coarse-textured stream benches, some within broad meadows. Bench communities were adjacent to A and B channels. Soils were wet and cold (cryic) and were usually Cryaquolls or Cryoborolls; one Fluvent was also sampled. Family particle size classes were fine-loamy and loamy-skeletal. Several shallow water tables were encountered.

Salix eastwoodiae, while most abundant in the Eastern Sierra Nevada Floristic Section (Sierra Nevada and Carson Range), was also sampled in the Lake Floristic Section (Santa Rosa Range). Goodrich (1981) noted it in the Toiyabe Range (Central Great Basin Floristic Section) but mentioned this sample may be *S. orestera*. Elevations on National Forest lands ranged from approximately 8,000 ft in both the Eastern Sierra Nevada and Lake Floristic Sections to over 10,300 ft in the Eastern Sierra Nevada Floristic Section. Valley bottom width was typically narrow or moderate, although this species was also noted in very broad valley bottoms in the Eastern Sierra Nevada Floristic Section. Gradients varied from very low to very high, although most were moderate. Communities typically occurred on seeps in various positions within large subalpine meadows; several, however, were on benches adjacent to A channels. Soils were wet and cold (classified as Cryaquolls and Cryoborolls), often with organic surface horizons. Family particle size classes were mostly fine-loamy. A few shallow water tables were encountered, although soils were typically wet to very moist.

Salix exigua is one of the most widespread willow species in the Western United States. It was sampled in all but the Mojave Floristic Section, but was noted at one location on the lower, east slope of the Spring Mountains. Elevations on National Forest lands ranged from 4,900 ft

on the Santa Rosa Range (Lake Floristic Section) to over 8,000 ft in the Calcareous Mountains (White Pine Range) and Central Great Basin (Toiyabe Range) Floristic Sections. Valley bottom widths varied from narrow to very broad, but most were moderate. Valley bottom gradient was typically very low, low, or moderate. Communities typically occupied benches or terraces adjacent to A, B, or C channels. Soils were usually Haploxerolls or Haploborolls, most with thick mollic epipedons, although Aquolls, Fluvents, Ochrepts, and Aquepts were also sampled. Family particle size classes varied; on stream bench communities they were loamy-skelatal or sandy-skeletal and on elevated terraces they were fine-loamy or clay-loamy. Several shallow water tables were encountered during sampling.

Salix geyeriana was notably absent from the Central Great Basin, Calcareous Mountains, and Mojave Floristic Sections. Elevations on National Forest lands ranged from approximately 5,800 ft in the Northeastern Great Basin Floristic Section to over 9,500 ft in the Eastern Sierra Nevada Floristic Section. *Salix lemmonii*, a similar species, is sympatric in many areas with *S. geyeriana* but generally occurs at higher elevations. Valley bottom width ranged from moderate to very broad, and gradient was typically low. Communities occupied benches adjacent to B channels, usually within meadows. Soils were Aquolls, Borolls, and some Xerolls, most with thick mollic epipedons. One Fluvent and several Histosols (Hemists, Saprists, and Fibrists) were also sampled. Family particle size classes were typically fine-loamy and clay-loamy. Nearly half the soils had shallow water tables.

Salix lasiandra was noted in all but the Mojave Floristic Section. In the Sierra Nevada, *S. lasiandra* var. *lasiandra* has glaucous leaves beneath; *S. lasiandra* var. *caudata* is glabrous beneath and also occurs here and throughout the remaining portions of the study area. This willow is considered a relatively low-elevation species (average elevation of 6,490 ft on National Forest lands). Elevations ranged from 4,900 ft in the Eastern Sierra Nevada Floristic Section to nearly 7,700 ft in the Central Great Basin Floristic Section. Valley bottom width was variable, but was typically moderate; gradient also varied but was mostly low. Most communities occupied benches adjacent to B channels, although some were adjacent to A and C channels. Soils were predominantly Xerolls, Borolls, or Aquolls, all typically with thick mollic epipedons; Fluvents and Fluventic Dystrochrepts, however, were also sampled. Family particle size classes were variable, ranging from clay-loamy to sandy-skeletal. Several shallow water tables were encountered.

Salix lasiolepis, while generally restricted to southern Nevada (Mojave and southern Calcareous Mountains Floristic Sections), also occurs in the Santa Rosa Range (Lake Floristic Section) of northern Nevada. It was also noted, though not sampled, in the Tonopah Floristic Section. It is the most common willow in the Spring Mountains (Mojave Floristic Section) and in the Grant and Quinn Canyon Ranges (southern Calcareous Mountains Floristic Section). Elevations on National Forest lands ranged from 5,500 ft in the Lake and Calcareous Mountains Floristic Sections to over 8,100 ft in the Spring Mountains. Valley bottom width was typically narrow,

and gradient was low or moderate. Communities occupied benches adjacent to A, B, and D (braided) channels. The latter type typically included ephemeral streams in the Santa Rosa Range. Communities in the Spring Mountains occurred either on side-slope seeps or on stream benches, while in the Grant and Quinn Ranges they were on stream benches. Soils were either Xerolls or Fluvents and were typically sandy-skeletal and loamy-skeletal. One shallow water table was encountered.

Salix lemmonii is most common in the Eastern Sierra Nevada Floristic Section but was also sampled in the Northeastern Great Basin, Lake, and Reno Floristic Sections. While this species and *Salix geyeriana* were often sympatric, *S. lemmonii* was sampled only once in the Lake Floristic Section. Elevations on National Forest lands in the Eastern Sierra Nevada Floristic Section ranged from less than 5,800 ft to over 10,000 ft. In the Jarbidge, Wildhorse, and Independence Mountains (Northeastern Great Basin Floristic Section), *S. lemmonii* generally occurred between 6,500 and 7,500 ft. Where *Salix lemmonii* and *S. geyeriana* are sympatric, *S. lemmonii* typically occurred at higher elevations. Valley bottom width ranged from narrow to very broad; gradient also varied, but was mostly low. Communities typically occupied benches adjacent to A and B channels, although a few communities occurred on seeps within meadows. At higher elevations in the Carson Range *S. lemmonii* formed a mosaic with *S. eastwoodiae*; at lower elevations it occurred in broad meadows with *S. geyeriana*. This species also grew along steep-gradient, tributary, A channels in the Carson Range. Soils were typically cold (cryic) and included Cryaquolls and Cryoborolls; Haploxerolls and Fluvents were also sampled. Family particle size classes were mostly fine-loamy, with some skeletal soils. A few shallow water tables were encountered during sampling.

Salix lutea was sampled in all but the Spring Mountains (Mojave Floristic Section). This typically low-elevation species ranged from approximately 5,000 ft on National Forest lands in the Santa Rosa Range (Lake Floristic Section) to over 8,700 ft on National Forest lands in the Eastern Sierra Nevada Floristic Section. *Salix lutea*, however, typically occurred below 7,500 ft in the study area. Valley bottom width ranged from narrow to very broad, but was typically moderate; gradient was mostly low. Communities occupied benches adjacent to B and A channels, although one seep community was sampled. Soils were variable and included Fluvents, Borolls, and Xerolls. Family particle size classes also varied; many were skeletal. A few shallow water tables were encountered.

The undescribed, nonglaucous form of *Salix lutea* was sampled only in the Central Great Basin Floristic Section (Toiyabe Range). Similar-appearing individuals were also noted in the Snake Range (Calcareous Mountains Floristic Section), but no collections were made to verify its occurrence. Where they were sympatric, this species generally occurred at higher elevations than the glaucous form of *Salix lutea* and ranged in elevation on National Forest lands from 7,000 ft to over 9,700 ft (the glaucous form ranged from approximately 6,800 ft to 7,600 ft in this portion of the study area). Valley bottom width, although variable, was typically moderate with low gradient. Communities typically occurred on benches adjacent to A and

B channels; two seep communities, however, were also sampled. Most soils had thick mollic epipedons and included Borolls and Xerolls. Two Histosols (Saprists and Hemists) were also sampled. Family particle size classes varied, but were typically fine-loamy and loamy-skeletal. Several shallow water tables were noted.

Salix orestera was sampled in the northern Ruby Mountains (Northeastern Great Basin Florisitic Section) and in the Sierra Nevada and Sweetwater Range (Eastern Sierra Nevada Floristic Section). This low willow was not sampled below 8,800 ft elevation and occurred at nearly 10,000 ft in the Eastern Sierra Nevada; it is expected to occur above timberline, but these sites were rarely sampled in this study. Glacial U-shaped valley bottoms in which this species occurred were typically moderate in width with variable gradient. Most communities were on well-drained, often convex, late-snowmelt slopes, although three bench communities associated with A channels were also sampled. In the northern Ruby Mountains, *Salix wolfii* generally occurs on adjacent wetter sites while *Salix eastwoodiae* is more common on wetter sites in the Eastern Sierra Nevada Floristic Section. Soils were cold, with most classified as Cyroborolls (Typic and Cumulic). One Histosol (Borofibrist) was also sampled. Family particle size classes were variable.

Salix planifolia was sampled only in the Eastern Sierra Nevada Floristic Section (Sierra Nevada and Sweetwater Range), usually above 9,000 ft. Relatively uncommon in the study area, this species was sampled only on seeps and adjacent to ponded water. Two varieties of *S. planifolia*, var. *planifolia* and var. *monica* (Bebb) Jeps., probably occur in the study area. Communities occurred in broad, low-gradient, valley bottoms (for example, cirque basins). Most occupied seeps, either on the toeslope or within meadows. Soils were cold or organic and included Cryaquolls and Borofibrists, with fine-loamy family particle size class. Soils were typically moist to wet.

Salix wolfii was sampled only in the northern Ruby Mountains (Northeastern Great Basin Floristic Section). Elevations on National Forest lands ranged from approximately 8,500 ft to over 9,600 ft. This low willow generally occupied wetter sites than *Salix orestera*, a common associate in this portion of the study area. Communities were sampled in moderate-to-broad valley bottoms (for example, glacial valley trains or cirque basins) with very low to low gradient, although steeper gradients were noted. Communities typically occupied benches adjacent to A and B channels, or were on seeps. Soils were cold and wet and were either organic or had an organic surface horizon. They included Cryoborolls, Cryaquepts, and Borohemists. Family particle size classes were typically clayey-loam and fine-loamy. Several shallow water tables were noted.

DISCUSSION

This paper includes general descriptions of the distribution and site characteristics of several willows that occur in the Humboldt and Toiyabe National Forests of Nevada and eastern California. While this information is limited in its application, the authors felt it would help land managers understand that willow species occupy a variety of sites and have different geographic distributions.

The information presented is not meant to be complete, even in its discussion of National Forest distribution. Additional population and individual life history studies will further aid land management decisions and improve riparian restoration projects.

REFERENCES

Argus, G. 1989. [Letter dated December 5, 1989]. On file at: U.S. Department of Agriculture, Forest Service, Intermountain Region, Ogden, UT.

Brunsfeld, S. J. 1991. [Personal communications]. Moscow, ID: University of Idaho, Department of Range Science.

Brunsfeld, S. J.; Johnson, F. D. 1985. Field guide to the willows of east-central Idaho. Bull. 39. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station. 95 p.

Cronquist, A.; Holmgren, A. H.; Holmgren, N. H.; Reveal, J. L. 1972. Intermountain flora: vascular plants of the Intermountain West, U.S.A. Vol. 1. New York: Hafner Publishing Company. 270 p.

Dorn, R. D. 1988. [Letter dated November 25, 1988]. On file at: U.S. Department of Agriculture, Forest Service, Intermountain Region, Ogden, UT.

Dorn, R. D. 1975. A systematic study of *Salix* section *Cordatae* in North America. Canadian Journal of Botany. 53: 1491-1522.

Goodrich, S. 1981. A floristic study of central Nevada. Provo, UT: Brigham Young University. 400 p. Thesis.

Hitchcock, C. L.; Cronquist, A. 1976. Flora of the Pacific Northwest. Seattle, WA: University of Washington Press. 730 p.

Manning, M. E.; Padgett, W. G. [In review]. Riparian community type classification for the Humboldt and Toiyabe National Forests, Nevada and eastern California. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region.

Munz, P. A. 1973. A California flora and supplement. Berkeley, CA: University of California Press. 1576 p. + 224 p. supplement.

Rosgen, D. L. 1985. A stream classification system. In: Riparian ecosystems and their management: reconciling conflicting uses; 1985 April 16-18; Tucson, AZ. Gen. Tech. Rep. RM-120. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 91-95.

U.S. Department of Agriculture. 1978. Valley bottom inventories with management implications. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 14 p.

Welsh, S. L.; Atwood, N. D.; Higgins, L. C.; Goodrich, S. 1987. A Utah flora. Great Basin Naturalist Memoir 9. Provo, UT: Brigham Young University. 894 p.

WILLOW COMMUNITY TYPES AS INFLUENCED BY VALLEY BOTTOM AND STREAM TYPES

Howard G. Hudak
Gary L. Ketcheson

ABSTRACT

An interdisciplinary team conducted inventories of willow community types in the Sawtooth National Forest in south-central Idaho. Stands dominated by one or several willow species were related to elevation, parent material, substrate, stream gradient, and configuration of the valley floor. Associations are described for stands dominated by mountain alder/northern black currant, water birch/red-osier dogwood, Booth willow, and Geyer willow. Understanding the relationship of riparian plants to their physical setting will increase successes in rehabilitating degraded areas by fostering use of species best suited for regeneration on different sites.

INTRODUCTION

The data presented here were obtained during both intensive and extensive field inventories over the past 5 years in the Sawtooth National Forest located in south-central Idaho. These data represent areas from unregulated (undammed) watersheds. Most of these areas have had some form of disturbance such as livestock grazing, timber harvesting, recreation activities, and access development in the form of roads and trails.

Approximately 250 miles of riparian areas have been inventoried by an Interdisciplinary Team (IDT). The team consisted of, at a minimum, representatives of the following functions: hydrology, soils, fisheries, range, and wildlife. Areas inventoried were from approximately 5,000 to 9,000 feet in elevation and dominant soil parent materials consisted of igneous (basalt and granitic), sedimentary (limestone), and metamorphic (micaceous schists). The data were collected using the procedures described in the draft Integrated Riparian Evaluation Guide (USDA 1991) being finalized by the Intermountain Region of the Forest Service.

DISCUSSION

From some of the other work done in the Intermountain Region (Brunsfeld and Johnson 1985; Youngblood and others 1985) we have learned that elevation is one of the factors that influences the distribution of willow communities. This is most likely a response by the plants to temperature.

In turn, temperature can be influenced by aspect or shading from adjacent plant communities and cold air drainage.

We also recognize that many willow communities occur as mixed stands, and rarely as one-species monoculture. These stands, which I will refer to as riparian complexes (Winward and Padgett 1987), may have as many as four different willow species present in a relatively small area. It is also common to have two and three species account for a major portion of the composition of some complexes. At times one or two species dominate the composition of an entire riparian complex.

Other factors besides elevation and the presence of free and unbound water may determine the presence of different willow communities and other riparian species on the landscape. The physical environment includes the landform (geomorphology) and soil or substrate types.

Landforms result from the weathering of geologic formations under a given climatic regime. Different geologic types weather at different rates due to the chemical composition of the bedrock. Weathering rates and other characteristics of bedrock types result in characteristically different landforms. Valley bottom shape, size, and gradient reflect the landform process and the hydraulic forces to which the materials have been subjected. Streams have been classified by Rosgen (1985) based on gradient, sinuosity, and particle size of substrate materials. We also use the valley bottom and stream types to describe the physical settings of riparian complexes.

This leads to the possible repetition of the same riparian complexes as one moves downstream within a watershed, and across watersheds. The repetition of riparian complexes on the landscape is a valuable tool for extrapolating information from one location to another. Therefore, the processes and the resulting physical settings (complexes) may and usually do repeat as one moves downstream within a watershed and across watersheds.

If we look at the vegetation stratification by elevation and species, and superimpose valley bottom type and stream type information as another layer of stratification, we can determine other factors that may play an important role in willow and other riparian species presence. Many riparian species require, or at least regenerate more successfully on, recently disturbed ground. Because these species are poor competitors in densely vegetated settings (Winward 1986), they require newly deposited or recently scoured sand or gravel bars on which to regenerate from seed. The stream type and flooding characteristics of different settings determine how and where material will sort and create nurse bars for willow and other species regeneration to take place.

If we utilize information on the relationship of riparian plants to their physical setting, we can talk intelligently about what would be expected in riparian areas and why many stands are of a mixed willow species composition intermingled with other riparian species.

SOME RESULTS OF OUR DATA ANALYSES

Mountain alder/northern black currant (ALIN/RIHU) dominant stands preferred A (68 percent) and B (26 percent) stream types (higher gradients) and relatively coarse-textured substrates (bedrock/boulder—21 percent; boulder/large cobble—50 percent; cobble—16 percent; gravel—16 percent). The fact that we did not find these stands in C channels may be a product of our limited sampling in C channels. Valley bottoms were typically narrow V's (79 percent).

Water birch/red-osier dogwood (BEOC/COSE) dominant stands were associated with mostly steeper gradient A (45 percent) and B (45 percent) stream types of coarse-textured substrates (bedrock/boulder—27 percent; boulder/large cobble—55 percent; cobble—18 percent). Valley bottoms were box canyon or narrow V (73 percent). BEOC/COSE was also found on narrow, flat-floored valleys (27 percent).

Booth willow (SABO) dominant stands were found mostly on moderate gradient streams of coarse-textured substrates (B—77 percent; C—15 percent) (bedrock—11 percent; boulder/large cobble—15 percent; cobble—31 percent; gravel—35 percent). Valley bottoms were narrow V or flat (85 percent).

Geyer willow (SAGE) dominant stands were found on mostly moderate gradient streams of moderate to finer textures (B—71 percent; C—20 percent; no A's) (boulder/cobble—14 percent; cobble—34 percent; gravel—31 percent; sand—6 percent). Valley bottoms were narrow V or flat (66 percent); low V or broad flat (17 percent); broad trough (14 percent).

The interaction between human influences and beaver populations can dramatically affect the amount and frequency of channel scour and gravel or sediment bar development and therefore potential sites for regeneration of riparian species. In addition, beaver activity can result in planting willow shoots while the animals work on their dams, which may later influence stand composition.

CONCLUSIONS

Understanding relationships between plants and their physical habitats gives us predictive capabilities for determining what species to use for rehabilitation of highly impacted riparian areas and understanding where a given complex is along successional pathways. This ability will increase our successes in riparian plantings by assisting us in using those species best suited for regeneration on different sites. Our data suggest that some species of willow are endemic to different types of parent material or show at a minimum a strong association to them. Based on our sampling, two examples of this are Lemmons willow to the granitic and Bebbs willow to sedimentary and metamorphic.

Inventorying riparian areas with an IDT was costly and time consuming, and many would say the cost was too high. The members of that IDT and National Forest managers they work for would disagree. This effort had value that will continue into the future for a better understanding of riparian resource management and implementation of cost-effective management programs for this resource area.

REFERENCES

Brunsfeld, S. J.; Johnson, F. D. 1985. Field guide to the willows of east-central Idaho. Bull. 39. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station. 95 p.

Rosgen, D. L. 1985. A stream classification system. In: Johnson, R. R.; Ziebell, C. D.; Patton, D. R.; [and others], tech. coords. Riparian ecosystems and their management: reconciling conflicting uses; 1985 April 16-18; Tucson, AZ. Gen. Tech. Rep. RM-120. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 91-95.

U.S. Department of Agriculture, Forest Service. 1991. [Draft] integrated riparian evaluation guide. Ogden, UT: Intermountain Region. 125 p.

Winward, A. H. 1986. Vegetation characteristics of riparian areas. In: Kie, J. G.; Laudenslayer, W. F., Jr., eds. Transactions of the Western Section of The Wildlife Society; 1986 January 23-25; Sparks, NV. Sacramento, CA: The Western Section of The Wildlife Society. 22: 98-101.

Winward, A. H.; Padgett, W. G. 1989. Special considerations when classifying riparian areas. In: Ferguson, D. E.; Morgan, Penelope; Johnson, F. D., compilers. Proceedings—land classifications based on vegetation: applications for resource management; 1987 November 17-19; Moscow, ID. Gen. Tech. Rep. INT-257. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 176-179.

Youngblood, A. P.; Padgett, W. G.; Winward, A. H. 1985. Riparian community type classification of eastern Idaho-western Wyoming. R4-Ecol. 85-01. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 78 p.

245

HIGH-WATER INDICATOR PLANTS ALONG IDAHO WATERWAYS

Roger Rosentreter

ABSTRACT

Plants restricted to and common under seasonally flooded conditions along Idaho waterways can be useful for managing and monitoring riparian areas. They can function as indicator plants that relate topography and channel capacity to annually fluctuating water levels. Indicator plants can also be useful in evaluating present and past stream hydrology conditions. The presence of these indicator species can help determine mean flood levels relative to the current water level. Stream channel geometry is highly variable over the length of a stream, and estimating mean high water can help one determine the sites suitable for rehabilitation.

OBJECTIVES

This study had two objectives. The first was to identify flood-sensitive riparian indicator species that would be useful for managing and monitoring riparian areas. The second was to identify aquatic vascular and lichen species that would serve as indicators of streamflow velocity.

INTRODUCTION

An understanding of riparian plant zonation can assist stream rehabilitation efforts. Some plants typically occur below mean high water, while others only occur above mean high water. These plants can help one interpret the landscape and the hydrology of a given site and guide efforts to achieve more successful riparian management (fig. 1).

Differences in species composition due to hydrologic characteristics of the channel and substrate stability have been noted by Hale (1950), Glime (1970), Gregory (1976), Rosentreter (1984), and Harris and others (1985). Riparian managers must have some understanding of plant moisture regimes, soil preferences, and tolerances to natural hydraulic forces as they use species patterns to "read" the hydrologic history. Many streams in the relatively arid Western United States experience highly variable discharges and lack gauge station information. Therefore, it is difficult to plan for the protection of the watershed from the next damaging peak discharge.

What can high-water indicator plants tell us about a stream? They can help us: (1) determine where the extreme high-water level occurs; (2) determine the mean high-water level (fig. 1); (3) determine the average stream channel capacity; (4) monitor streamflows without the use of expensive instruments; (5) monitor changes in the streamside geomorphology (erosion, deposition, stream channel geometry); (6) determine substrate and bank stability; and (7) provide a reference point from which to locate new plantings along the stream channel.

Extreme High Water

Extreme high water is an important consideration along streams. The structure, location, and character of the stream is largely determined by the extreme high-water events. Extreme high-water events are often referred to by their likelihood of reoccurring as 20-, 50-, or 100-year floods. Such floods erode banks, move and deposit sediment, cause new stream channels to form, and are more significant than many people realize. This point cannot be overemphasized. Before artificial structures are built or vegetative rehabilitation efforts are employed, the present vegetation's condition and structure should be analyzed thoroughly. Historical evidence of past floods is often portrayed in the present vegetation. Management plans for a stream segment should take into account the level and degree of extreme flooding that may occur.

High-water events, such as the 50- or 100-year flood, are generally predicted using models of watershed characteristics and runoff. Plants, however, can provide important clues about extreme events. Riparian gallery forests, for example, are often comprised of trees that establish after major flood events (Hansen 1985). The age of the trees can be combined with hydrologic analysis to identify extreme

Figure 1—Typical zonation along the Salmon River in Idaho. Arrow points out the hackberry trees (*Celtis reticulata*) at the high-water level.

flood dates and levels. The occurrence of disturbance-adapted plants can provide information on the height and date of the last extreme high-water event. The lack of plant establishment can provide clues on how recently an extreme event occurred. These vegetative clues can serve as a second information source to validate or question a hydrologic analysis. The longer lived the vegetation, the longer the history of stream channel flood events they reflect. For example, an annual plant is of little value, while a long-lived tree or shrub can give you a much better clue about the past flood history.

The age of certain plants present in the upper flood zone can be used to date the occurrence of the last extreme high flood level. Gregory (1976) noted that the time elapsed since the last flood (high stream discharge) could be measured by the size of the shield lichen thalli (*Parmelia* spp.) on recolonized rock. The presence of lichen growth has been used to date glacial processes (Beschel 1973). Similarly, the presence of lichens and specific vascular plants can be used to record fluvial processes.

Mean High Water

The mean high water relative to the present stream level can also be very misleading. In 1991, much of the Western United States experienced its fifth year of drought, and many riparian managers have never seen the local streams with average flows. Therefore, careful analysis of streamside vegetation is essential to determine average streamflows. In years of more-normal stream discharges, it is often possible to see nonvegetative evidence of the last high-water mark on streams without gauges. These nonvegetative markers or indicators include stranded material such as driftwood, small twigs, seeds, wash lines, lines left by muddy water or foam, or ice scars on the trees (fig. 2). Scars on trees can be aged by analysis of the annual ring growth.

Stream Channel Capacity

An indication of stream channel capacity can be determined by measuring the depth and width where high water occurs. The volume of water in a channel when in flood can only be determined by physically measuring it during the flood stage (cubic feet per second). However, the relative velocities of different stream channel segments can be estimated from the slope or gradient, the size of the gravels moved by the stream, and by the plant species present (Harris and others 1985). Tolerance to disturbance by flood velocities varies between species. Thus, the presence and absence of certain species within the flood zone can provide clues to the velocity of these flood events. Plants can also alter the velocity of flood waters by providing a more-resistant channel.

Monitoring Streamflows

Streamflows can be estimated without the use of expensive instruments by monitoring plant species composition and position along the streambank. These plants serve as natural monitors of environmental conditions thoughout a season and over several years. For example, an area that once supported sedges dries out with lower streamflows

Figure 2—Ice scars on the trees and shrubs along the stream are sometimes visible (pointer).

and becomes occupied by sagebrush or other upland species. Annual vegetation monitoring will elucidate these vegetation and hydrologic changes.

Stream Geomorphology

Changes in the stream's hydrology and geomorphology due to erosion, deposition, and sediment load may be monitored by periodically mapping streamside vegetation (Gregory 1976). These relative vegetation changes can be used to direct management decisions.

Stream Channel Stability

Plants are critical to the stability of the streambank. Roots stabilize the bank itself and the aboveground biomass reduces the erosive force of the water on the banks. It has been recognized that species provide differing levels of protection. Stream channel stability can thus be analyzed by observing the distribution and type of vegetation present. For example, bedrock is more stable than gravel in the stream channel, yet the stability of the rocks can be further enhanced by the presence and type of vegetation on the rock. Within a given stream channel, rocks lacking vegetative cover may not be as stable as those colonized by vegetation (Pentecost 1977; Rosentreter 1984).

Rehabilitation With Shrubs

The best locations for planting shrubs along the stream channel can be determined by noting and mimicking the placement of the current riparian vegetation. Restoration or rehabilitation projects often involve planting willows or other shrubs. In arid portions of the West, it is important to plant these shrubs close enough to the stream for additional water uptake. However, these same plants may be dislodged and washed away with high-water events if placed too close to the stream's flow. Therefore, understanding soil moisture regimes and stream channel morphology helps in the development of successful riparian plantings.

19

Generally, the inside of a stream's bend provides a fairly large, optimal planting zone, while the optimal zone of the outside bend is usually quite narrow. Projects often fall short of their goals because these important factors have not been adequately considered.

STUDY AREA

The study area was southern Idaho, south of the main Salmon River. Streams were surveyed for 2 years at various times of the year to determine seasonal water levels. Streams ranged in size from small, ephemeral, first-order streams to larger fourth-order river systems. Large river systems included the Boise, Bruneau, Jarbidge, Deadwood, Payette, Owyhee, Snake, Sesech, and middle, south, and main Salmon Rivers. Small streams were predominantly tributaries of the Bruneau, Jarbidge, and Snake Rivers.

Study sites varied in elevation from 2,134 m on Birch Creek in southeastern Idaho to below 609 m on the Snake River in southwestern Idaho. Topography and climate for this geographic area is varied, with vegetative communities ranging from salt-desert shrub communities (*Atriplex confertifolia*) to subalpine fir forests (*Abies lasiocarpa*). Most of the study sites were surrounded by sagebrush grasslands (*Artemisia tridentata* with *Agropyron*, *Festuca*, or *Bromus tectorum*).

METHODS

Vascular plants in and adjacent to riparian areas were collected. Special attention was given to plants occurring in the transition zone between riparian and upland communities. Voucher collections were deposited at the College of Idaho (CIC), Boise State University's Snake River Plains herbarium (SRP), and the Boise District, Bureau of Land Management. Specimen data included: (a) substrate; (b) substrate stability; (c) slope; (d) associated species; (e) location relative to the stream channel; (f) location relative to mean high water; (g) stream type (size); and (h) any other unique habitat characteristics. These qualitative environmental characteristics provided the basis for classification into indicator classes. Nomenclature of vascular plants follows Hitchcock and Cronquist (1973).

The location of mean high water is one of the most critical environmental factors for identifying species sensitive to flooding. Since most of these streams were ungauged, an indicator method of determining mean high water was utilized. This method is based on earlier research that correlated the occurrence of the long-lived lichen, *Dermatocarpon reticulatum*, with mean high water (Rosentreter 1984). The height of this lichen on studied streams was used as an indicator of mean high water.

Sampling of lichens and mosses consisted of paired transects in contrasting hydraulic conditions. I recognized distinct physical stream segments as pool, run, riffle, pocket water, and backwater (eddies) as defined by Primbs and Andrews (1990). For example, a transect pair might have one transect in the run segment of the streambed with a strong direct hydraulic current and a second transect at the same rapid but in a weaker backwater (eddy) current. Paired transects allowed comparison of species responses to hydraulic conditions unaltered by elevation or by other changing environmental conditions along the river's length. Sites altered by humans were noted but were not included in the sampling.

Paired transect sampling was done in mid-to-late summer during low water periods, allowing easy access to seasonally flooded areas. Line transects ran perpendicular to the shoreline. At each decimeter point along the transect line, species presence was noted and the following qualitative environmental data recorded: (1) location in the current; (2) rock type; (3) degree of siltation; and (4) slope.

Mosses and lichens were identified to species when possible. Species of the lichen genus *Verrucaria* were not separated. Mosses that were sometimes difficult to distinguish without sporophytes, or were physically battered by flood waters, were recorded as *Barbula rubiginosa*. Nomenclature of lichens and mosses follows Egan (1987) and Crum and others (1973). Vouchers of lichens and mosses were deposited at the University of Montana herbarium (MONTU) and in the private herbaria of Bruce McCune and R. Rosentreter.

HIGH-WATER INDICATOR SPECIES

Zonation of plant species is most definitive on the steep slopes of narrow stream channels (fig. 3). If the purpose of identifying riparian indicators is to provide information on flood events for any given stream, it is advisable to view the narrower segments first. Our desert streams often display zonation in narrow canyons, with less zonation as they become incised or braided in the broader alluvial valleys.

Many riparian plant species are primary colonizers of areas created by periodic natural flooding. Species that colonize areas disturbed by floods were also identified in riparian areas with anthropogenic disturbances (increasers). Because of this, stream segments less disturbed by various anthropogenic factors may provide better information than do the disturbed segments. Note that because some riparian species will colonize equally an anthropogenic disturbance and a flood-related disturbance, careful analysis is needed to be sure the disturbance patterns observed are the result of natural floods.

Stream Channel Geometry
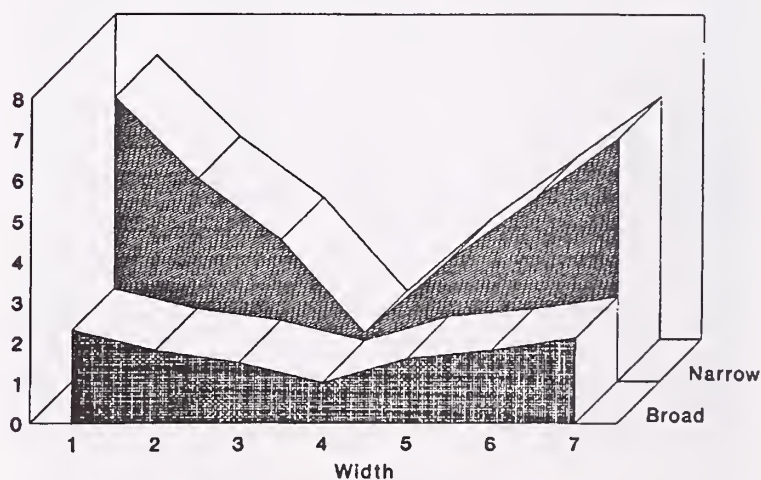
Figure 3—Comparision of narrow and broad stream channels in cross section.

Many of the plants that grow near streams are intolerant of any amount of flooding, and their presence marked the zone above extreme high water. Examples of these are big sagebrush and most bunchgrass species. Cliff-dwelling plants such as alumroot (*Heuchera*) and ivesia (*Ivesia*), both common on southern Idaho's rhyolitic canyon walls, are examples of species intolerant of flooding. Table 1 gives examples of zonation indicators on two typical streams in Idaho. Table 2 lists species identified in this study that only occurred above high-water line (intolerant of any flooding). These species cannot survive anaerobic conditions for more than a few days. Their presence indicates that the stream has not flooded these areas recently, at least not for an extended period of time.

Species occurrence above or below mean high water appeared to depend strongly on three environmental characteristics: (1) riparian condition, (2) elevation, and (3) stream type. Stream type includes the gradient of the stream, the velocity of high-water events, the substrate moved by high-water events, and the moisture conditions throughout the year. Table 1 summarizes the zonation for two typical streams in southern Idaho. Table 2 identifies species useful for indicating sites above mean high water on the streams surveyed in this study. Tables 3 and 4 identify species useful as indicators of increasing or decreasing abundance, based on their presence and frequency on poor- or good-condition riparian areas, respectively. These species may not be useful indicators in other geographic and climatic

areas, but some are likely useful indicators thoughout the Great Basin and arid portions of the Pacific Northwest. These lists differ from the national list of facultative and obligate wetland plant species that occur in wetlands (Reed 1988). I consider the national list to be too general and lacking emphasis on management or monitoring values. The monitoring of increasers and decreasers is a common concept in rangeland management. The use of the increaser or decreaser concept presented here can assist range managers in monitoring riparian areas (tables 3 and 4).

Since the same stream may contain both good and poor condition segments, streams must be viewed as a whole. These interconnected systems are best rehabilitated by knowledge of seasonal flood levels. Monitoring indicator species can be used to measure the amount of downcutting on degraded streams. In the case of incised streams, rock outcrops or boulders may contain evidence of past water levels. Lichens or mosses on the rock outcrops reflect the fluctuating water levels (fig. 4). Terrestrial crustose lichens are very slow growing (Webber and Andrews 1973), and their presence can clearly define the high flood level prior to stream degradation (Gregory 1976). Another example of lichens marking the highwater level found in this study was the orange lichen *Xanthoria fallax*, which grows on cottonwood trees in riparian areas (table 2). High floods kill the lichen on the base of the cottonwood trees to the level of flooding, leaving a distinctive line until the next event.

Table 1—Indicator species on two typical streams in Idaho

Vegetation zone	Stream A Ponderosa-ninebark habitat	Stream B Sagebrush-bluebunch wheatgrass habitat
Terrestrial zone	ninebark stonecrop	sagebrush wheatgrass
Highwater	highwater moss	alkali buttercup
Flooded zone	riverbank wildrye willow aster	brookgrass
Below low water	tar lichen	algae

Table 2—Plants that occur only above mean high water in southern Idaho (intolerant of flooding)

Plant type	Common name	Scientific name
Woody plants	big sagebrush rabbitbrush	*Artemisia tridentata* *Chrysothamnus* spp.
Forbs	alumroot Bailey ivesia prickly phlox Bruneau River phlox stonecrop cactus	*Heuchera* spp. *Ivesia baileyi* *Leptodactylon pungens* *L. glabrum* *Sedum* spp. *Opuntia, Pediocatus*
Grasses	bunchgrasses three-awn	*Agropyron* spp. *Aristida longiseta*
Lichens	wall lichen orange lichen shield lichen	*Lecanora muralis* *Xanthoria fallax* *Xanthoparmelia* spp.

Table 3—Increasers found in periodically flooded areas along streams of southern Idaho

Plant type	Common name	Scientific name
Woody plants	lead plant	*Amorpha fruticosa*
	Louisiana sagebrush	*Artemisia ludoviciana*
	poison ivy	*Toxicodendron radicans*
	greasewood	*Sarcobatus vermiculatus*
Forbs	horseweed	*Conyza canadensis*
	spearmint	*Mentha spicata*
	tansy ragwort	*Tanacetum vulgaris*
	dogbane	*Apocynum androsaemifolium*
	watercress	*Rorippa* spp.
	nettles	*Urtica dioica*
	water mudwort	*Limosella aquatica*
	woolyheads	*Psilocarpus oregonus*
	white sweetclover	*Melilotus alba*
	yellow sweetclover	*M. officinalis*
	golden hairy aster	*Chrysopsis villosa*
Graminoids	inland saltgrass	*Distichlis spicata*
	rabbitfoot	*Polypogon monspeliensis*
	Canada bluegrass	*Poa compressa*
	barnyard grass	*Echinochloa crusgalli*
	trailing sedge	*Juncus scopiderous*
	foxtail barley	*Hordeum jubatum*
	quackgrass	*Agropyron repens*
	Baltic sedge	*Juncus balticus*
Lichens	silver skinned	*Dermatocarpon reticulatum*

Table 4—Decreasers found in periodically flooded areas along streams of southern Idaho

Plant type	Common name	Scientific name
Woody plants	cottonwoods	*Populus trichocarpa*
	willows	*Salix* spp.
	hackberry	*Celtis reticulata*
Grasses	Great Basin wildrye	*Elymus*
	Nevada bluegrass	*Poa nevadensis*
	sloughgrass	*Beckmannia syzigachne*
	alkali-grass	*Puccinellia* spp.

Figure 4—Lichens on rock outcrops (pointer) clearly reflect fluctuating water levels for this stream.

SPECIES OCCURRENCE AND OTHER ENVIRONMENTAL FACTORS

Besides indicating the mean high-water level, some plants are valuable indicators of other environmental conditions. For example, corydalis (*Corydalis*) and tansy ragwort (*Tanacetum vulgaris*) both occur on silty soils. However, corydalis is found along good-condition streams at higher elevations, while tansy ragwort grows along poor-condition streams at low elevations.

Disturbed sandy soils, present in both good- and poor-condition streams, are often occupied by licorice root (*Glycyrrhiza lepidata*), hairy golden aster (*Chrysopsis villosa*), or cocklebur (*Xanthium strumarium*) (table 5). Willow aster (*Aster hespericus*) is more frequent in rocky areas, and only on sites with cryic soils. Torrent sedge (*Carex nudata*) is also restricted to cryic soils, but to those with less rock. Both torrent sedge and willow aster occur along most of the larger rivers in the Pacific Northwest (table 1). Three species were found to be especially informative. In Idaho, riverbank wildrye (*Elymus innovatus*) is found only below mean high water, especially on large river systems (table 6). I have observed this species throughout the Pacific Northwest. However, it is rarely collected and is lacking from many regional plant lists due to its restricted habitat.

Eddy moss (*Scouleria aquatica*) is a true bryophyte restricted to the zone below high water (table 6). As its common name implies, it occurs predominantly in locations with weaker currents and in eddies behind large rocks (fig. 5). Eddy moss grows firmly anchored to rock and is fairly resistant to the abrasive forces of the current.

Pepperwort (*Marsilea vestita*), a small perennial plant related to ferns, resembles a four-leaf clover growing in dry

22

Table 5—Increasers found below high water in poor-condition riparian areas in southern Idaho

Plant type	Common name	Scientific name
Forbs	licorice root	*Glycyrrhiza lepidata*
	silverweed cinquefoil	*Potentilla anserina*
	purple loosestrife	*Lythrum salicaria*
	cocklebur	*Xanthium strumarium*
	navarretia	*Navarretia breweri*
	Scouler popcorn flower	*Plagibothrys scouleri*
Graminoids	flat sedge	*Cyperus acuminatus*

Table 6—Decreasers found below high water in good-condition riparian areas in southern Idaho

Plant type	Common name	Scientific name
Forbs	water knotweed	*Polygonum amphibium*
	beggarticks	*Bidens frondosa, B. cernua*
	willow aster	*Aster hespericus*
	corydalis	*Corydalis caseana*
	speedwell	*Veronica* spp.
	monkey flower	*Mimulus guttatus*
	watercress	*Rorippa* spp.
	nodding buttercup	*Ranunculus natans*
	alkali buttercup	*R. cymbalaria*
	basalt buttercup	*R. oresterus*
	pepperwort	*Marsilea vestita*
Graminoids	water foxtail	*Alopecurus geniculatus*
	brookgrass	*Catabrosa aquatica*
	tufted hairgrass	*Deschampsia caespitosa*
	fowl mannagrass	*Glyceria striata*
	switchgrass	*Panicum occidentale*
	riverbank wildrye	*Elymus innovatus*
	torrent sedge	*Carex nudata*
	spike rush	*Eleocharis palustris*
	common reed	*Phragmites communis*
	reed canarygrass	*Phalaris arundinacea*
	Nebraska sedge	*Carex nebrascensis*
Lichens	tar lichen	*Verrucaria* spp.
	aspicilia	*Aspicilia aquatica*
Mosses	eddy moss	*Scouleria aquatica*
	highwater moss	*Barbula rubiginosa*
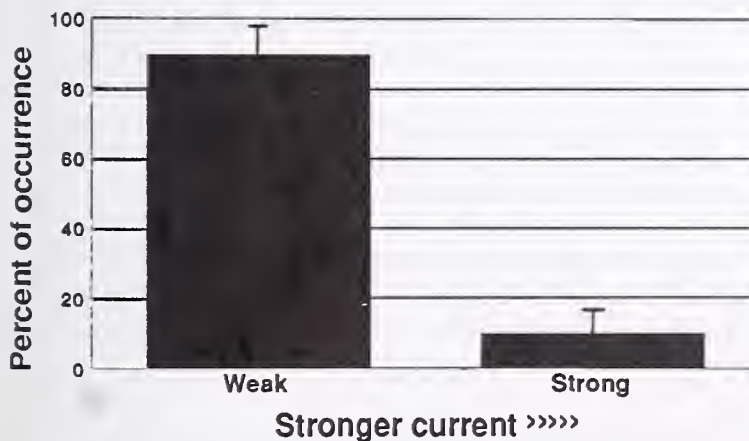
Figure 5—Percent of eddy moss in paired transects by current velocity.

mud along desert streams and lakes below high water (table 6). Pepperwort prefers sites that flood in the spring but are dry and hot by midsummer. It is common in many of the ephemeral streams in the sagebrush desert in Idaho and other portions of the Great Basin.

EXCEPTIONS

The use of indicator species to interpret stream history is not without its exceptions. Noting these exceptions is essential. For example, seepage areas change the normal distribution pattern of indicator plants. Additional water allows aquatic or water-dependent species to occur higher above the streambed. These wet areas should not be considered when surveying for high-water indicators. Irregular topography also creates problems in interpretation.

While transects on vertical walls may show distinct zones at the high-water level, transects through rough topography often do not. This irregularity is similar to the irregularity of vegetation zones on a mountain with a broken topography. Vegetation zones along streams are not always abrupt. Rather than a zone of abrupt presence or absence, it may be a change in relative abundance, so that the species' positions overlap.

Large dams often reduce or halt natural seasonal stream fluctuations, changing the zonation along a stream. Road construction and other artificial disturbances can also directly alter a streambank. Several of the rivers studied had one or both of their banks reinforced due to road or railroad construction. Such disturbed segments along streams are best avoided when evaluating a stream's history based on its present vegetation.

CONCLUSIONS

Interpreting a stream's history is possible if riparian indicator plant species are identified and their relative position to the topography is evaluated. Species identification is the first step to interpretation of high-water indicators. Each geographic and elevational area will have some indicator species. Understanding the general pattern of streamside zonation and the influence of hydrology on the system helps interpret the present vegetation patterns. The better the inventory of the streamside vegetation, the more useful indicator species will be in the management of riparian areas.

This paper presents some of the more commonly encountered species in southern Idaho. Some of these species may also be useful indicators in other parts of the Great Basin and arid portions of the Pacific Northwest.

ACKNOWLEDGMENTS

REFERENCES

Beschel, R. E. 1973. Lichens as a measure of the age of recent moraines. Arctic and Alpine Research. 5: 303-309.

Craw, R. C. 1976. Streamside bryophyte zonations. New Zealand Journal of Botany. 14: 19-28.

Crum, H. A.; Steere, W. C.; Anderson, L. E. 1973. A new list of mosses of North America north of Mexico. The Bryologist. 76: 85-130.

Egan, R. S. 1987. A fifth checklist of the lichen-forming, lichenicolous and allied fungi of the continental United States and Canada. The Bryologist. 90(2): 77-173.

Glime, J. M. 1970. Zonation of bryophytes in the headwaters of a New Hampshire stream. Rhodora. 72: 276-279.

Gregory, K. L. 1976. Lichens and determination of river channel capacity. Earth Surface Processes and Landforms. 1: 273-285.

Hale, M. E. 1950. The lichens of Aton forest, Connecticut. The Bryologist. 53: 181-213.

Hansen, P. L. 1985. An ecological study of the vegetation of Theodore Roosevelt National Park, North Dakota. Vermillion, SD: University of South Dakota. 117 p. Thesis.

Harris, R. R.; Risser, R. J.; Fox, C. A. 1985. A method for evaluating streamflow discharge-plant species occurrence patterns on headwater streams. In: Johnson, R. R.; Ziebel, C. D.; Patton, D. R.; Ffolliott, P. F.; Hamre, R. H., coords. Riparian ecosystems and their management: reconciling conflicting uses. First North American Riparian Conference. Gen. Tech. Rep. RM-120. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 87-90.

Hitchcock, C. L.; Cronquist, A. 1973. Flora of the Pacific Northwest. Seattle, WA: University of Washington Press. 730 p.

Primbs, E. R. J.; Andrews, J. L. 1990. Stream segments defined. Journal of the Idaho Academy of Science. 26(1): 88-91.

Reed, P. D., Jr. 1988. National list of plant species that occur in wetlands: national summary. Biol. Rep. 88(24). Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service. 244 p.

Rosentreter, R. 1984. The zonation of mosses and lichens along the Salmon River in Idaho. Northwest Science. 58(2): 108-117.

Webber, P. J.; Andrews, J. T. 1973. Lichenomentry: a commentary. Arctic and Alpine Research. 5: 295-302.

A COMPARISON BETWEEN XERORIPARIAN AND UPLAND VEGETATION OF BEAVER DAM SLOPE, UTAH, AS DESERT TORTOISE HABITAT

E. Durant McArthur
Stewart C. Sanderson

ABSTRACT

The Beaver Dam Slope of extreme southwestern Utah, extending just into Arizona, is historic desert tortoise habitat that has been grazed by domestic livestock for over 100 years. It is composed of a large bajada dissected by intervening arroyos. The arroyo vegetation can be considered to be xeroriparian. It is provided with surface moisture in excess of local rainfall only on infrequent occasions. Paired 0.01-ha (1/40-acre) relevé vegetation plots were established systematically in arroyo and paired upland plots. Species were identified and plots were otherwise vegetatively and physically characterized. Data were collected each April, 1989-91, and subjected to TWINSPAN indicator species analysis and analysis of variance. Of 105 species identified (two trees, 24 shrubs, eight cacti, 12 grasses, 59 forbs), 30 were common enough to be used in TWINSPAN analysis. Fourteen were preferentially associated with xeroriparian habitats, three with upland habitats, and 13 were non-preferential in habitat association. Annual plant cover values were correlated with precipitation and varied from less than 3 percent in 1989 to about 25 percent in 1991.

INTRODUCTION

The Beaver Dam Slope (BDS) in extreme southwestern Utah, extending just into Arizona, is a large, dissected bajada sloping south and southwestward from the Beaver Dam Mountains toward the Virgin River and its tributary Beaver Dam Wash. The total area of BDS is about 242.4 km² (93.6 miles²) as determined from Baird's (1990) map. The BDS is the lowest and hottest part of Utah and is at the northern edge of the Mojave Desert (Greer and others 1981; Meyer 1978). It is near the ecotone between the Great Basin and Mojave Desert vegetative community types (Meyer 1978; Tueller and others 1991). However, it lies wholly below the 1,220-m (4,000-ft) elevational contour and is quite Mojavean in nature (Meyer 1978).

The BDS is home to the desert tortoise (*Gopherus agassizii*) near the northern limit of the species' range. Woodbury and Hardy (1948) performed an early, classic study on the

BDS tortoises in the 1930's and early 1940's. Desert tortoises also occur east of the Beaver Dam Mountains north and east of St. George at a northern latitude approximately the same as that of the BDS limit (Patterson 1982). The entire Mojave desert tortoise population north and west of the Colorado River received emergency Endangered Species Act protection in 1989 (Federal Register). Subsequently, the tortoises in this region were permanently protected (Federal Register 1990). Because of an earlier population decline in the Woodbury and Hardy Study Area on the BDS a 101-km² (39-mi²) area on Utah's BDS was declared, in 1980, critical habitat for the desert tortoise and its tortoise population was declared "threatened." This area subsequently has been managed by the Bureau of Land Management (BLM), U.S. Department of the Interior, under multiple-use principles, but with emphasis on the well-being of desert tortoises. The BDS has been grazed by domestic livestock (cattle and sheep) for well over 100 years (Bostick 1990). For the past three or four decades it has been grazed solely by cattle in the fall, winter, and spring. Desert tortoises are distributed across the BDS bajada but use the dissecting arroyos differently than they do the intervening uplands (Woodbury and Hardy 1948). Tortoises winter in dens under a caliche layer in the arroyo walls. During the summer they are active on the uplands and arroyos.

This study characterizes, in a general way, the vegetation of the dissecting arroyos and intervening uplands on the Beaver Dam Slope bajada. Since tortoises use the arroyos and uplands differently, this study tests the hypothesis that vegetation patterns of uplands and arroyos differ. We used the Johnson and others (1984) xeroriparian definition, which, we believe, matches the arroyo vegetation type of the BDS: "Mesic to xeric habitat-type with average annual moisture higher than surrounding uplands, but provided with surface moisture in excess of local rainfall only on infrequent occasions (usually for less than one month per year)."

This study is part of a larger project designed to assay habitat and biological characteristics of desert tortoises at the northern extent of their distributional range (Esque and others 1991; McArthur and Sanderson 1991).

METHODS

Quantitative vegetational sampling was accomplished on 30 paired (total of 60) plots (relevés) on a grid system on the BDS in Utah bounded by 113°53'20" to 113°59'30" W. Longitude and 37°0'30" to 37°02'15" N. Latitude (fig. 1) (relevé = a basic field unit in phytosociology that is uniform

in floristic composition and of uniform relief and soil type—Allaby 1985). Plots were located near U.S. Public Land Survey section corners in a paired manner. A plot was located 10 m (32.8 ft) upslope from the section corner. If the section corner was on an upland site (the usual case), the arroyo (lowland) counterpart was located in the nearest arroyo at least 1 m (3.3 ft) lower in elevation than the upland plot (fig. 2). In the reverse situation, where the section corner was in an arroyo, the upland site was located on the nearest upland site, usually less than 30 m (98.4 ft) distant. Ten supplementary pairs of plots were located on the eastern half of the study area where BLM personnel felt desert tortoise activity was more intense and population was larger. These plots were located 200 m (656 ft) directly east (90°) of section corners. The plots are 0.01 ha (1/40 acre), circular in form, and marked with steel reinforcing bars at the center for the upland plots and at the perimeter nearest the section corner for the arroyo plots. The bars were driven into the ground until only 10 cm (4 inches) was exposed. The steel bars were intended to be permanent and were identified with aluminum tags wired to their tops. Data were collected for all 60 plots in 1989 and 1991. In 1990, data were not collected from the 10 supplementary plot pairs (20 plots) (fig. 1).

The vegetative sampling procedure used was the relevé method of the Zurich-Montpellier School of Phytosociology (Braun-Blanquet 1927). Data collected included a species list for each plot with each species assigned a scaled value for cover (projected crown cover) and sociability (dispersion of individuals). The data recorded at each plot included date, workers, U.S. Public Land Survey designation, parent material of the soil, slope of the site (percent), exposure (degrees from north), vegetational type, unusual species, evidence of use, seral stage, vegetational condition and trend, and all species of occurrence (fig. 3). Each plot was photographed (fig. 4). The plot data were analyzed using analysis of variance procedures (SAS 1985) and the multivariate
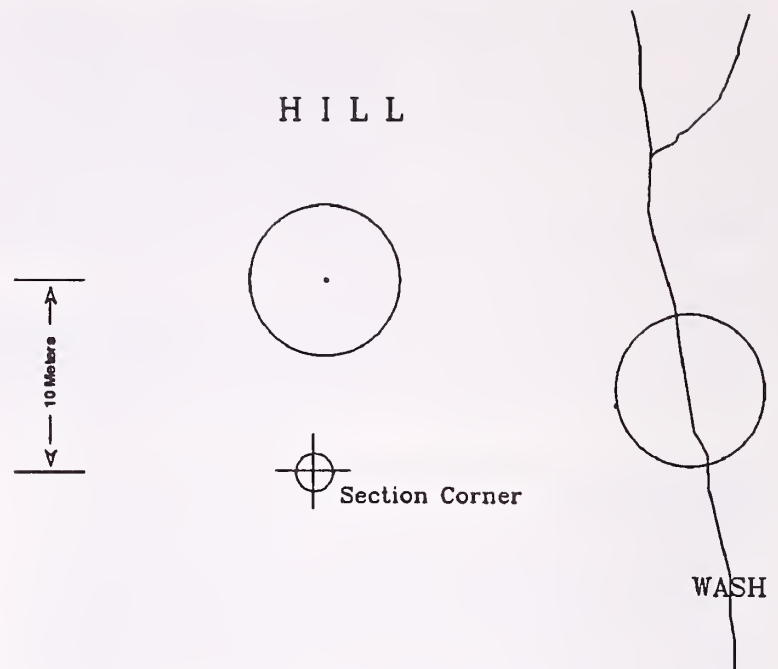
Figure 2—Schematic design illustrating how plots were set up.

community ecology analysis program TWINSPAN (Gauch 1982; Hill 1979). Plants were identified and characterized using Welsh and others (1987) and Albee and others (1988). Climatological data were obtained from National Oceanic and Atmospheric Administration reports (NOAA 1988-91).

RESULTS AND DISCUSSION

We encountered a total of 105 species in our plots including two trees, 24 shrubs, eight cacti, 12 grasses, and 59 forbs (table 1). All of the trees, shrubs, and cacti were native plants. One tree, Joshua tree (*Yucca brevifolia*), was quite common; the other, singleleaf pinyon (*Pinus monophylla*) occurred only as a seedling in a solitary plot. The 12 grass species included seven native perennials, two native annuals, and three introduced annuals. The 59 forb species included 45 native and two introduced annuals and 12 native perennials. Our plots were established within the larger Beaver Dam Wash study area of Baird (1990), who identified some 608 species and 10 infraspecific plant taxa including 134 introduced species. Baird's study area included some true riparian areas with perennial waterflow as well as foothill and mountainous areas; our area was confined to the BDS bajada.

The pattern of vegetation follows a general descending elevational gradient from a mosaic of pinyon (*Pinus monophylla*)-juniper (*Juniperus osteosperma*) and chaparral communities on the Beaver Dam Mountains to blackbrush (*Coleogyne ramosissima*) to Joshua tree to creosote bush (*Larrea tridentata*)-bursage (*Ambrosia dumosa*) communities on the BDS (Baird 1990; Woodbury and Hardy 1948). Baird (1990) described other more restricted Beaver Dam Wash communities as the desert almond (*Prunus fasciculata*) (= our xeroriparian community), catclaw acacia (*Acacia greggii*), sand desert, and riparian communities. Our study sites included the blackbrush, Joshua tree, creosote bush, and desert almond communities but not the pinyon-juniper, chaparral, catclaw acacia, or riparian
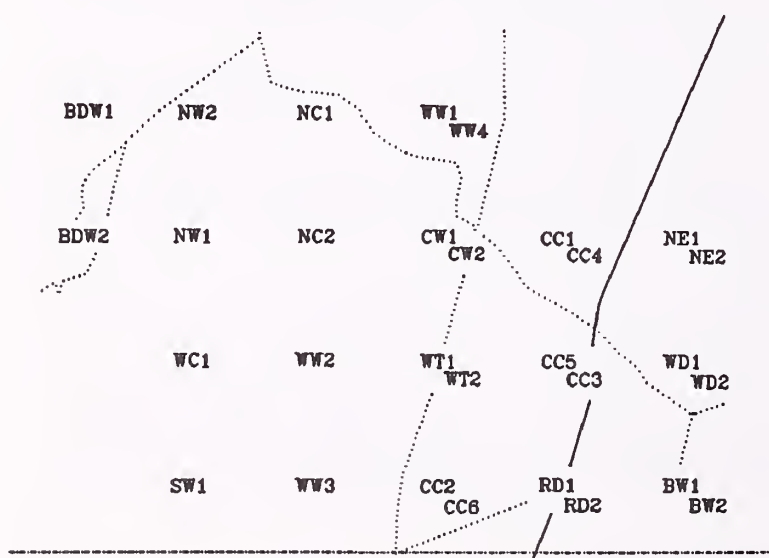

Figure 1—Schematic locations of paired study plots on the Beaver Dam Slope. The solid line is old U.S. Highway 91; the broken line at the bottom is the Utah-Arizona state boundary; the dotted lines are gravel or dirt roads. Plots are identified by landmarks or location, for example, WW = Welcome Wash, WT = water tank, NC = north central.

Plot no._____NC-U1____Place name_____NORTH CENTRAL 1_____ Date_____4/2/91_____
T, R, Section_____T43S R19W 10, 11, 14, 15_____UTM grid coordinates_____
Marker used as base_____SECTION CORNER_____ Upland or wash_____UPLAND_____
Heading and distance from marker_____30M AT 125°_____ Elevation difference with paired plot_____+5M_____
Plot access_____
Plot size_____1/40 ACRE_____Slope_____3%_____Aspect_____105°_____ Elevation_____3058'_____
Parent material_____ Soil series_____ Soil texture_____
Soil stability_____
Vegetational type_____LARREA, BURSAGE, BLACKBRUSH, JOSHUA_____ Seral stage_____CLIMAX_____
Evidence of historic use_____
Signs of tortoise activity_____
Plot photographed?___Y___ Workers_____SCS, SFB_____
===

RECONNAISSANCE DATA
cover/sociability

Trees		Forbs	
-none-		Astragalus nuttallianus	+ 1
		Chaenactis fremontii	+ 1
Shrubs		Descurainia pinnata	+ 1
Acamptopappus sphaerocephala	+ 1	Draba verna	+ 1
Ambrosia dumosa	1 1	Eriogonum	+ 1
Coleogyne ramosissima	+ 1	Eriophyllum lanosum	+ 1
Ephedra nevadensis (grazed)	+ 1	Erodium cicutarium	2 1
Gutierrezia microcephala	+ 1	Eucrypta micrantha	+ 1
Krameria grayi	+ 1	Gilia inconspicua	+ 1
Lycium andersonii	+ 1	Lepidium densiflorum	+ 1
Thamnosma montana	+ 1	Lesquerella tenella	+ 1
		Plantago patagonica	+ 1
Graminoids			
Bromus rubens	1 1		
Oryzopsis hymenoides	+ 1		
Schismus barbatus	+ 1		

===
COVER BY TYPE
Vascular Plants____30____%   Bare soil____40__%   Litter____20___%   Rock >1cm_____30____%   Cryptogams____+___%

RELATIVE COMPOSITION OF LIVING COVER
Trees_____0____%   Shrubs_____21_____%   Graminoids_____5_____%   Forbs_____10_____%
===

Cover classes		Sociability classes	
< 1%	+	Growing as single, widely spaced individuals	- 1
1 - 5%	1	Small groups	- 2
6 - 25%	2	In small patches	- 3
26 - 50%	3	Extensive patches	- 4
51 - 75%	4	In nearly pure stands	- 5
76 - 95%	5		
>95%	6		

Figure 3—An example data sheet (NC-1 upland, 1991).

Figure 4—Photographs of study plots: (A) Upland site of WT1, 1989; (B) Arroyo site of WT1, 1989.

Table 1—Plant species recorded from Beaver Dam Slope study plots, 1989-91

Tree species	Number of occurrences[1]
Pinus monophylla	1
Yucca brevifolia	23

Shrub species	
Acamptopappus sphaerocephalus	31
Ambrosia dumosa	53
Ambrosia eriocentra	2
Ambrosia species	1
Ceratoides lanata	7
Chrysothamnus paniculatus	5
Chrysothamnus viscidiflorus	1
Coleogyne ramosissima	7
Encelia frutescens	8
Ephedra nevadensis	24
Ephedra viridis	1
Eriogonum fasciculatum	6
Gutierrezia microcephala	18
Hymenoclea salsola	18
Krameria grayi	33
Krameria parvifolia	19
Larrea tridentata	44
Lepidium fremontii	2
Lycium andersonii	24
Lycium cooperi	1
Prunus fasciculata	10
Psilostrophe cooperi	7
Salazaria mexicana	9
Thamnosma montana	38

Cactus species	
Echinocereus engelmanii	2
Ferocactus acanthoides	1
Mammillaria tetrancistra	2
Neolloydia johnsonii	6
Opuntia acanthocarpa	16
Opuntia basilaris	3
Opuntia echinocarpa	22
Opuntia erinaceae	5

Perennial grass species	
Aristida purpurea	8
Erioneuron pilosum	33
Hilaria rigida	6
Muhlenbergia porteri	19
Sporobolus cryptandrus	1
Stipa hymenoides	4
Tridens muticus	1

Annual grass species	
Bromus rubens[2]	59
Bromus tectorum[2]	1
Festuca octoflora	2
Poa bigelovii	1
Schismus barbatus[2]	56

Perennial forb species	
Anemone tuberosa	1
Baileya multiradiata	27
Calochortus flexuosus	8
Delphinium andersonii	3
Eriogonium inflatum	11
Euphorbia albomarginata	2
Happlopappus species	2
Mirabilis pumila	1

(con.)

communities. Many species, including some of the community dominants (for example, blackbrush, creosote bush, bursage), occur across community types.

Ephemeral plant presence and density can change dramatically from year to year depending mainly on moisture conditions. Figure 5 summarizes the weather conditions that impacted our study. In general, conditions were hot (the normal condition) but drier than usual when we started our study (1989). Moisture conditions improved for critical periods over the last two-thirds of the study period (1990-91). However, precipitation patterns can be extremely erratic in these desert regions. For example, although the Lytle Ranch weather station, about 5 km (3 mi) north of the northwest corner of fig. 1, was much wetter than the St. George weather station, 28 km (17.5 mi) north-northeast of the northeast corner of the study area, during the last two years of the study period (fig. 5), it was much drier (2.95 cm (1.16 inches)) than St. George (5.56 cm (2.19 inches)) and Bunkerville (6.25 cm (2.46 inches)) during the April-October 1989 period (NOAA 1989). Bunkerville, NV, is 28.5 km (17.5 mi) south-southwest of the southwest corner of the study area.

Our sampling design (fig. 2) paired adjacent upland and xeroriparian plots so we could compare community composition and characteristics. TWINSPAN analysis showed species associations that distinguish between upland and xeroriparian communities across the bajada slope (table 2).

Table 1 (Con.)

Perennial forb species	Number of occurrences[1]
Senecio douglasii	6
Sphaeralcea grossulariifolia	2
Stephanomeria pauciflora	25
Triteleia grandiflora	3

Annual forb species[3]

Astragalus nuttallianus	52
Chaenactis fremontii	11
Chorizanthe brevicornu	4
Cryptantha barbigera	3
Cryptantha circumscissa	2
Cryptantha pterocarya	19
Descurainia pinnata	26
Descurainia sophia	12
Draba verna[2]	44
Eriastrum diffusum	5
Eriastrum eremicum	2
Eriogonum species	13
Eriogonum deflexum	3
Eriophyllum lanosum	34
Eriophyllum wallacei	1
Erodium cicutarium[2]	57
Eucrypta micrantha	12
Gilia inconspicua	35
Langloisia schottii	1
Lepidium densiflorum	59
Lepidium virginicum	1
Lesquerella tenella	19
Linanthus bigelovii	10
Lupinus sparsiflorus	1
Mentzelia albicaulis	5
Nama demissum	1
Nemacladus glanduliferus	1
Oenothera primiveris	13
Pectocarya species	32
Phacelia ambigua	6
Phacelia coerulea	1
Phacelia fremontii	7
Phacelia species	1
Plagiobothrys arizonicus	6
Plantago patagonica	44
Rafinesquia neomexicana	9
Silene antirrhina	3
Streptanthella longirostris	9
Stylocline micropoides	2

[1]Number of occurrences out of 60 possible.

[2]Introduced plants.

[3]There were eight additional unknown annual forbs—two with two occurrences, and six with one occurrence each.

Fourteen species (eight shrubs, one cactus, two perennial grasses, and three perennial forbs) were classified as positive preferentials, that is, they were associated with arroyo habitats. Three shrub species, creosote bush, goldenhead (*Acamptopappus sphaerocephalus*), and range ratany (*Krameria parviflora*) were negative preferentials, that is, they were associated with uplands. Thirteen species (one tree, five shrubs, two cacti, two perennial grasses, one perennial forb, and two introduced annuals) were nonpreferentials, that is, they were as likely to occur on uplands as in arroyos. The other 75 species were not common enough to be of use in the TWINSPAN analysis. Table 3 shows the mean

— St. George Normal
----- St. George Study Period
·········· Lytle Ranch Study Period

1 = Apr. - Sep., 1988; 2 = Oct. - Mar. 1988-89;
3 = Apr. - Sep., 1989; 4 = Oct. - Mar. 1989-90;
5 = Apr. - Sep., 1990; 6 = Oct. - Mar. 1990-91.
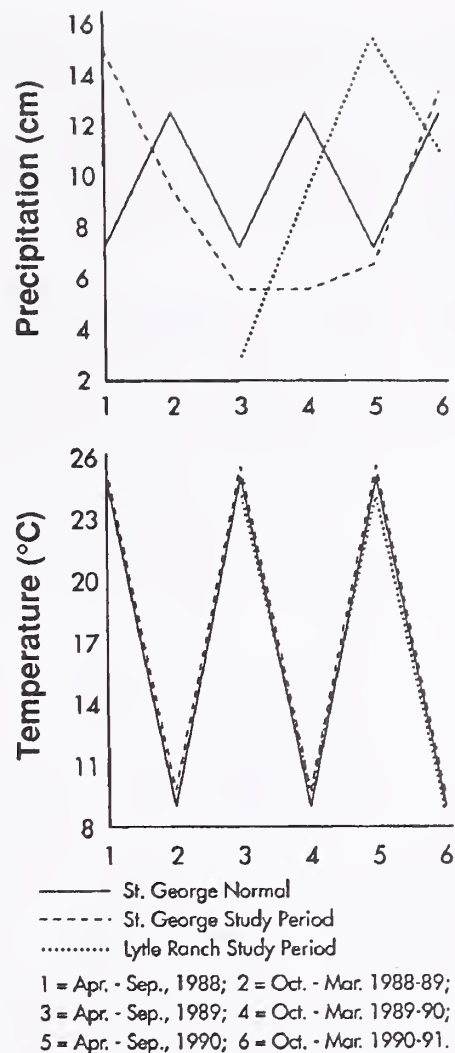
Figure 5—Climatic summary of St. George and Lytle Ranch weather stations. The "St. George Normal" value is based on long-term averages (NOAA 1991).

Table 2—Positive, non- and negative preferential xeroriparian species from Beaver Dam Slope plots using 1989 and 1991 data by TWINSPAN analysis

Positive preferentials	Nonpreferentials
Chrysothamnus paniculatus	*Yucca brevifolia*
Encelia frutescens	*Ambrosia dumosa*
Eriogonum fasciculatum	*Ephedra nevadensis*
Gutierrezia microcephala	*Krameria grayi*
Hymenoclea salsola	*Lycium andersonii*
Prunus fasciculata	*Opuntia acanthocarpa*
Psilostrophe cooperi	*Opuntia echinocarpa*
Salazaria mexicana	*Thamnosma montana*
Neolloydia johnsonii	*Bromus rubens*
Aristida purpurea	*Erioneuron pilosum*
Hilaria rigida	*Muhlenbergia porteri*
Baileya multiradiata	*Eriogonum inflatum*
Senecio douglasii	*Eriodium cicutarium*
Stephanomeria pauciflora	

Negative preferentials

Acamptopappus sphaerocephalus
Krameria parviflora
Larrea tridentata

values for cover on upland and arroyo sites for 1989. None of the mean values was significantly ($p < 0.05$) different between upland and arroyo sites. This may be due to the considerable variation between and within sites. Although these mean values (grouping plant classes and species) were not different on upland and arroyo sites TWINSPAN analysis differentiated between uplands and arroyos (using species distribution patterns).

The two nonpreferential exotic annuals listed in table 2, red brome (*Bromus rubens*) and storksbill (*Erodium circutarium*), were common during all 3 years of study. Many other annual herbs were encountered (table 1); however, they were not common enough to be treated in the TWINSPAN analysis over the entire study period. In 1991, species frequency and cover were dramatically higher than in the other years of study (table 4) reflecting more favorable climatic (higher precipitation) conditions (fig. 5) and allowing us to make a TWINSPAN preferential habitat comparison using annuals for that year. This bloom of native annual forbs revealed an interesting pattern in their relative distributions (fig. 6). Twenty-two of the upland plots exhibited patterns suggesting a distinctive annual species association featuring Fremont dustymaiden (*Chaenactis fremontii*), slender bladderpod (*Lesquerella tenella*), and ambiguous phacelia (*Phacelia ambigua*). Nineteen of the arroyo plots exhibited patterns suggesting an alternate distinctive annual species association featuring winged-nut crypthanth (*Cryptantha pterocarya*), flixweed (*Descurainia sophia*), desert eucrypta (*Eucrypta micrantha*), Bigelow linanthus (*Linanthus bigelovii*), and early evening primrose (*Oenothera primiveris*). Table 4 illustrates the variable nature of annual species presence and productivity. The common annual grasses were red brome and Mediterranean grass (*Schismus barbatus*). The latter species was present only in trace amounts in 1989 but became common in 1990 and 1991. We believe this difference was due to more favorable moisture conditions in 1990 and 1991 than existed in 1989.

Our study shows that the xeroriparian communities differ from adjacent upland communities in perennial (mainly shrub) plant composition, but not in the frequency or cover of the common introduced annuals (red brome, storksbill,

Table 4—Beaver Dam Slope annual species and percent cover comparisons among years[1]

	Grasses		Forbs	
Year	Number of species	Percent cover	Number of species	Percent cover
1989	1.05 ± 0.22b	2.76 ± 1.83c	1.72 ± 1.24b	1.07 ± 0.98c
1990	2.03 ± 0.28a	5.05 ± 4.47b	9.98 ± 2.97a	7.96 ± 4.02b
1991	1.93 ± 0.31a	10.40 ± 7.90a	9.23 ± 2.09a	14.32 ± 9.75a

[1]Values are means ± standard deviations. Mean values in columns followed by different letters are significantly ($p < 0.05$) different by Tukey means comparison test.
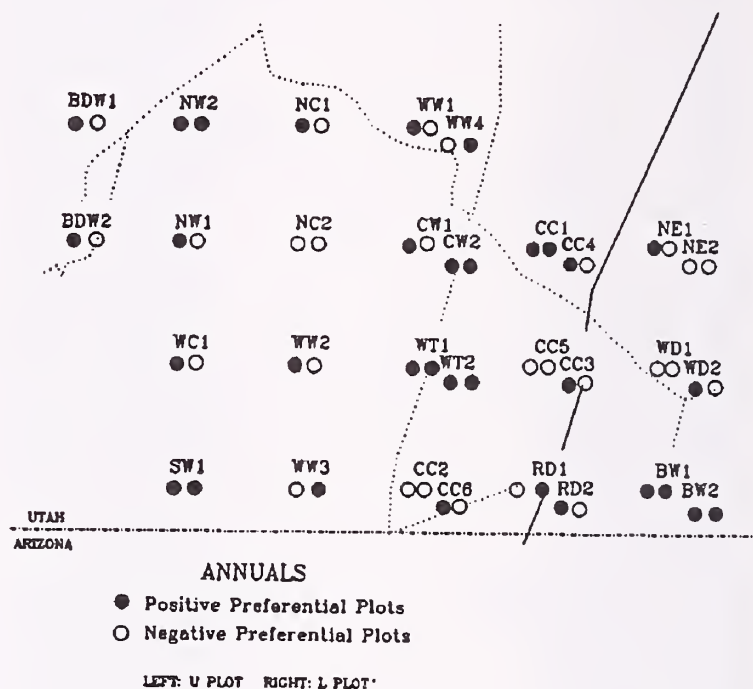
Figure 6—Preferential vegetation association of annuals on Beaver Dam Slope study plots, 1991, using TWINSPAN analysis.

Table 3—Comparison of cover value on upland and arroyo plots on Beaver Dam Slope, 1989 data[1]

Plot type	N	Vascular plants	Bare ground	Litter
Arroyo	30	30.23 ± 14.42	38.93 ± 16.44	20.83 ± 8.31
Upland	30	28.33 ± 8.64	41.93 ± 19.20	21.33 ± 9.19
		Rock	Cryptogams	Trees
Arroyo		29.00 ± 10.78	2.22 ± 9.21	1.94 ± 4.52
Upland		26.67 ± 14.43	1.68 ± 5.49	0.52 ± 1.03
		Shrubs	Grasses	Forbs
Arroyo		15.10 ± 8.52	4.33 ± 3.19	2.20 ± 1.29
Upland		16.63 ± 7.92	3.65 ± 1.76	1.70 ± 1.42

[1]The values given are means ± standard deviations. Mean sums for arroyos and uplands exceed 100 percent because cover is sometime layered. No mean values were significantly different ($p < 0.05$) between arroyo and upland plots.

Mediterranean grass). Native annual forbs, when present, tend to associate in different patterns on the uplands than in the arroyos. It is interesting to contemplate whether, prior to the sustained livestock grazing of the BDS, shrub interspaces were occupied by annuals or perennials or devoid of vegetation. Woodbury and Hardy (1948) and Bostick (1990) suggested that perennial grasses, bush muhly (*Muhlenbergia porteri*), Indian ricegrass (*Stipa hymenoides*), and big galleta (*Hilaria rigida*), formed a savannah with the warm desert shrubs on some ecological sites.

How do the vegetation patterns correlate with or characterize desert tortoise habitat? We believe the arroyos with more shrubs and a rougher topography serve well as den sites and provide more succulent forage in dry periods. The uplands provide a much larger area and under favorable moisture conditions an abundance of easily accessible forage.

ACKNOWLEDGMENTS

REFERENCES

Albee, B. J.; Shultz, L. M.; Goodrich, S. 1988. Atlas of the vascular plants of Utah. Occas. Publ. 7. Salt Lake City, UT: Utah Museum of Natural History. 675 p.

Allaby, M., ed. 1985. The Oxford dictionary of natural history. New York: Oxford University Press. 688 p.

Baird, G. I. 1990. A floristic survey of the Beaver Dam Wash, Utah. Provo, UT: Brigham Young University. 146 p. Thesis.

Bostick, V. 1990. The desert tortoise in relation to cattle grazing. Rangelands. 12: 149-151.

Braun-Blanquet, J. 1927. Plant sociology: the study of plant communities. Translated from the German by Fuller, G. D.; Conard, H. S. New York: McGraw-Hill. 439 p.

Esque, T. C.; DeFalco, L. A.; Bury, R. B. 1991. Nutrition and foraging ecology of the desert tortoise: FY 1990 annual report. Fort Collins, CO: U.S. Department of the Interior, Fish and Wildlife Service, National Ecology Research Center. 50 p.

Federal Register. 1989. Endangered and threatened wildlife and plants; desert tortoise; proposed rule. October 18, 1989.

Federal Register. 1990. Endangered and threatened wildlife and plants; determination of threatened status for the Mojave population for desert tortoise. Final rule. April 2, 1990.

Gauch, H. G., Jr. 1982. Multivariate analysis in community ecology. Cambridge, England: Cambridge University Press. 298 p.

Greer, D. C.; Gurgel, K. D.; Wahlquist, W. L.; Christy, H. A.; Peterson, G. B. 1981. Atlas of Utah. Provo, UT: Brigham Young University Press. 300 p.

Hill, M. O. 1979. TWINSPAN—a FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Ithaca, NY: Cornell University, Section of Ecology and Systematics. 90 p.

Johnson, R. R.; Carothers, S. W.; Simpson, J. M. 1984. A riparian classification system. In: Warner, R. E.; Hendrix, K. M., eds. California riparian systems: ecology, conservation, and productive management: California riparian systems conference; 1981 September 17-19; Davis, CA. Berkeley, CA: University of California Press: 375-382.

McArthur, E. D.; Sanderson, S. C. 1991. Annual report of ecological studies of desert tortoise habitat. Provo, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Shrub Sciences Laboratory. 21 p.

Meyer, S. E. 1978. Some factors governing plant distributions in the Mojave-Intermountain transition zone. Great Basin Naturalist Memoirs. 2: 197-207.

National Oceanic and Atmospheric Administration. 1988-91. Climatological data, Nevada and Utah. Volumes 90-93. Asheville, NC: U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Patterson, R. 1982. The distribution of the desert tortoise (*Gopherus agassizii*). In: Bury, R. Bruce, ed. North American tortoises: conservation and ecology. Wildlife Res. Rep. 12. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service: 51-55.

SAS Institute Inc. 1985. SAS procedures guide for personal computers, version 6 edition. Cary, NC: SAS Institute Inc. 373 p.

Tueller, P. T.; Tausch, R. J.; Bostick, V. 1991. Species and plant community distribution in a Mojave-Great Basin desert transition. Vegetatio. 92: 133-150.

Welsh, S. L.; Atwood, N. D.; Goodrich, S.; Higgins, L. C., eds. 1987. A Utah flora. Great Basin Naturalist. 9: 1-894.

Woodbury, A. M.; Hardy, R. 1948. Studies of the desert tortoise, *Gopherus agassizii*. Ecological Monographs. 18: 145-200.

RIPARIAN ECOLOGY IN ZION NATIONAL PARK, UTAH

K. T. Harper
S. C. Sanderson
E. D. McArthur

ABSTRACT

Approximately 40 km (24.9 mi) of perennial streams occur in Zion National Park. The dominant trees along these streams are Acer negundo, A. grandidentatum, Fraxinus velutina, Populus fremontii, *and* Quercus gambelii. *The introduced shrub,* Tamarix ramosissima, *is currently about as common as the native shrub,* Salix exigua, *on disturbed stream edges. Other native shrubs in the pioneer stages of succession are* Baccharis emoryi *and* Chrysothamnus nauseosus. *Woody species of late-seral stages include* Abies concolor, Acer glabrum, A. grandidentatum, A. negundo, Jamesia americana, Juniperus scopulorum, Mahonia repens, Pachystima myrsinites, Pseudotsuga menziesii, Quercus gambelii, *and* Symphoricarpos oreophilus. *Riparian areas are scenic focal points and support the richest avian fauna in the Park. The aquatic environments also harbor endemic snail and fish species and numerous algal, insect, and lower plant species that occur in the Park only in the riparian zone.*

INTRODUCTION

The riparian community is more important to the Zion National Park (ZNP) environment than its small area might indicate (40 km or 24.9 mi of perennial streams). Riparian communities provide esthetic enrichment to the arid, red rock landscape that typifies ZNP, and they hold a magnetic appeal for both humans and the native animals of the area. The riparian strips are especially rich in birds, but the diversity and population density of mammals, reptiles, amphibians, and a host of invertebrate species are also greater there than elsewhere in the Park. In addition, the streams and springs harbor unusual fishes and snails (Behle 1943; Woodbury 1933).

The well-vegetated, cool water courses have been natural migration routes for both plant and animal species for millenia. As a result, many terrestrial and aquatic species penetrate into the region only along waterways.

This study is part of a larger project mapping the vegetation of ZNP (Harper and others 1988, 1989, 1990).

PRIOR WORK

The first description of the riparian communities of ZNP appears to be that of Woodbury (1933). His monographic study treats the more common species of both plants and animals that characterize the major plant communities of the Park. His study also describes the relationship of the major plant communities to the physical environments of the region.

A recent classification of southern Utah riparian habitats (Padgett and Youngblood 1986) has been prepared for use on landscapes managed by the Forest Service, U.S. Department of Agriculture. Accordingly, the report emphasizes higher elevation areas than are traversed by streams in ZNP (1,189-1,829 m or 3,900-6,000 ft above sea level). As a result, the classification does not include most of the riparian types found within the Park. The recent statewide classification of riparian community types in Utah by Padgett and others (1989) is similarly designed to serve the needs of the Forest Service and does not include the most common community types of the riparian zone in ZNP.

A paper published in 1988 will be useful to anyone studying the riparian zone in the Park. Webb and Brotherson (1988) report on the vegetation of three streams in Washington County, UT. They describe the vegetation along Ash, Leeds, and Santa Clara Creeks with samples being collected at 93-m (305-ft) elevational intervals from headwaters to the streams' confluences with the Virgin River. They identify major species, the elevational distribution of each, and the ways in which the species associate in time or space to form the assemblages observed under field conditions. Of the streams studied, Ash Creek approaches ZNP most closely—it parallels the western border of the Kolob section of the Park. The riparian vegetation of Ash Creek is much like that observed along La Verkin Creek in the Kolob section, North Creek, which drains from the northeast to unite with the Virgin River near the hamlet of Virgin, and the North Fork of the Virgin River, which flows down the main canyon near Park headquarters.

An official U.S. Weather Bureau station is maintained near Park headquarters in the main canyon near Springdale. Mean annual temperature at that station is 16.2 °C (61.2 °F). Mean temperature for January is 4.3 °C (39.7 °F) and 29.1 °C (84.3 °F) for July. Mean annual precipitation is 37.1 cm (14.6 inches) with about 40 percent of the total falling during the growing season (April-September) (Eubank and Brough 1979).

METHODS

This report is part of a large survey of all vegetational types within the Park. The riparian results are based on 19 study plots (each 0.01 ha [0.025 acre] in size). In an attempt to obtain equal coverage of vegetational conditions throughout the Park, samples were taken at all cadastral survey section corners within the Park. Since some of the more rugged portions of the Park have not been surveyed, section lines were projected across unmapped areas on 7.5-minute quadrangle topographic maps. Samples were then taken at intersections of north-south and east-west section lines. Since riparian zones are usually represented by narrow bands along streams in rugged terrain, section corners rarely fell directly on the riparian strip. Thus, to obtain samples of the riparian zone from all portions of the Park, additional sample plots were taken opportunistically or as near to section corners as possible. Plots were sampled in the following general areas: Bear Trap Canyon, Black Ridge, Camp Creek, Coal Pit Wash, Langston Canyon, North Fork of the Virgin River, Parunuweap Canyon, South Fork of Taylor Creek, The Barracks, and near Twin Brothers (fig. 1). More plots (nine) were sampled along the North Fork of the Virgin than elsewhere, because that area receives more visitors and is more likely to receive management attention.

Plots were circular wherever the riparian zone was wide enough. In narrow canyons, rectangular plots of 0.01 ha

area were established. Once the outlines of a study plot were established, the vegetation was surveyed using a procedure developed by the Zurich-Montpellier school of phytosociology (Braun-Blanquet 1927). The worker listed all species rooted on the plot and assigned a cover value for projected crown cover to each. A sociability index (the degree to which individuals of a species are clumped in space) was also assigned to each species. Each plot's location was pinpricked onto an areal photograph, its Universal Traverse Mercator grid location was recorded, and it was photographed using color print film. Elevation, aspect, and slope of each plot was recorded as was geologic parent material, evidences of prior use, and seral stage (early succession on erosional surfaces, midseral, or late seral). An attempt to classify site condition (intensity of previous use and resultant damage to the system) and trend (recovering or continuing to deteriorate) was made for each study area.

Soil samples were collected at three plots having near-average vegetational composition. Those samples were analyzed for a variety of physical and chemical characteristics in an attempt to determine whether a vegetational community differed markedly from others represented in the Park in respect to its abiotic environment. Soils were analyzed by the Soil Analytical Laboratory, Department of Agronomy and Horticulture, Brigham Young University, using standard procedures.

We have synthesized the vegetational data by identifying prevalent species. Curtis (1959) suggested that one should compute a species density parameter for each community described. Species density was defined as the average number of species for study plot used to describe the community. He identified prevalent species by arranging all species encountered in plots used to describe a community in decreasing order of frequency of occurrence in those plots. He then counted down that ordering of species to a number equal to the species density value for the community: those species were called prevalents. Prevalent species represent about 27 percent of all species encountered in the riparian community, but they account for over 57 percent of all species occurrences in the 19 plots (table 1). Thus, prevalent species are abundant species that are well adapted to the environment of concern. Prevalent species lists provide an efficient system for training naive workers concerning the taxonomic necessities for working in a particular community. Workers that recognize a community's prevalent species will be able to identify over 57 percent of the species of occurrence in the average study plot—the remainder of the species on the plot will be drawn from a much larger pool of species and will have to be identified as they are encountered.

We also follow Curtis (1959) in recognizing "modal" species for the community. Modal species are those that reach maximum regional abundance in the community of concern. We have also computed an index of homogeneity and an index of distinctiveness for the riparian community using definitions developed by Curtis. The index of homogeneity is computed by dividing the sum percent presence of prevalent species by the sum percent presence of all species encountered in the study plots. That value conveys some idea about how similar the flora of one study plot will be to that of another in the same community. The index of distinctiveness is computed by dividing the percent sum presence of modal species by the percent sum presence of prevalent species in the same community. This index tells one what
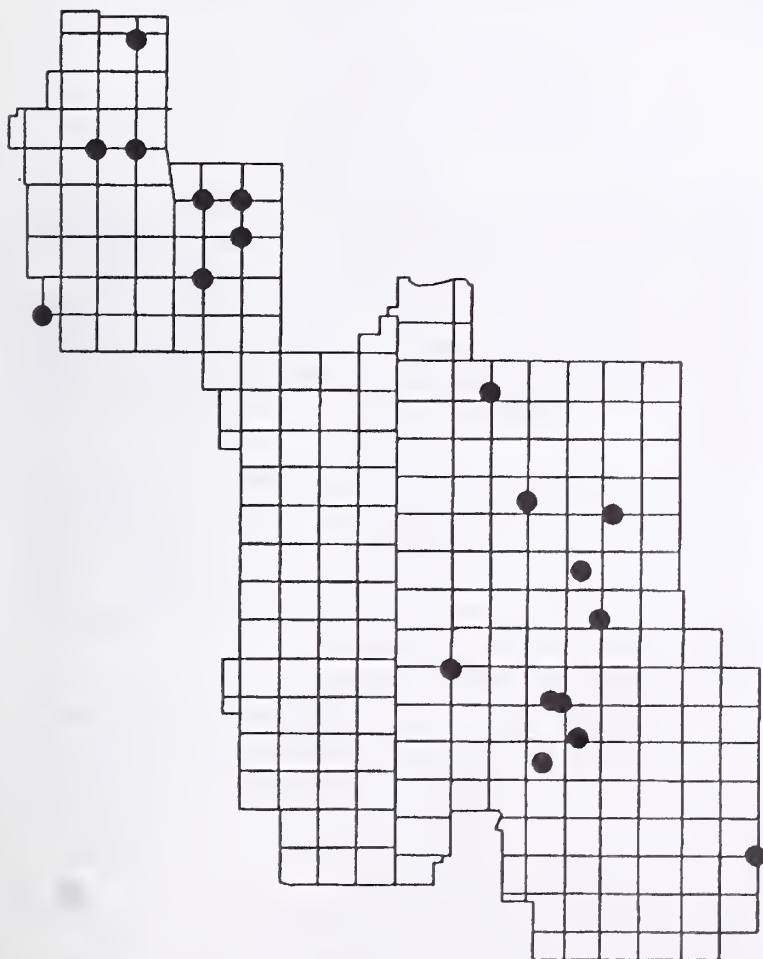

Figure 1—Locations of riparian study plots, ●, at Zion National Park superimposed on the sampling grids for the larger vegetation sampling project.

Table 1—Prevalent species of the riparian community of Zion National Park. Prevalents that are also modal are asterisked. Species followed by (I) are introduced; all other species are native. Various characteristics of each species are listed

Species	Plots of occurrence	Lifeform[1]	Longevity[2]	Foliage longevity[3]	Successional status[4]
	Percent				
Acer negundo*	63	Mes	P	D	C
Poa fendleriana	47	He	P	E	C
Bromus tectorum (I)	47	T	A	—	P
Artemisia ludoviciana*	42	He	P	D	S
B. diandrus* (I)	42	T	A	—	P
Quercus gambelii	37	Mi	P	D	S
Acer grandidentatum	37	Mi	P	D	C
B. ciliatus*	37	He	P	D	C
Senecio spartioides*	37	He	P	D	C
Heterotheca villosa	37	He	P	D	S
Fraxinus velutina*	32	Mes	P	D	C
Stephanomeria tenuifolia*	32	He	P	D	S
Populus fremontii*	32	Mes	P	D	S
Arabis perennans	32	He	P	D	S
Equisetum hyemale*	26	He	P	E	C
Penstemon rostriflorus*	26	C	P	D	S
Phacelia heterophylla	26	He	B,P	D	S
Eriogonum racemosum	26	He	P	D	S
Solidago sparsiflora	26	He	P	D	C
Cirsium arizonicum*	26	He	P	D	S
Zauschneria latifolia*	26	He	P	D	S
Cystopteris fragilis*	21	He	P	D	C
Poa pratensis* (I)	21	He	P	D	S
Taraxacum officinale*	21	He	P	D	S
Thelypodium laxiflorum*	21	He	B	D	S

[1]Mes = mesophanerophyte (dormant buds 8-30 m above soil surface), Mi = microphanerophyte (buds 2-8 m above soil), N = nanophanerophyte (buds 0.25-2 m above soil), C = chamaephyte (buds <0.25 m above soil), He = hemicryptophyte (buds at surface), G = geophyte (buds several cm below soil surface), T = therophyte (annual).
[2]A = annual, B = biennial, P = perennial.
[3]D = annually deciduous, E = evergreen.
[4]P = pioneer, S = midseral, C = climax (late seral).

proportion of the prevalent species achieve maximum regional abundance in the community of concern. Communities of low distinctiveness closely resemble other communities in the region.

Finally, we have used the literature and our collective experience to assemble as much management-relevant information as possible concerning each prevalent species. Such information is presented in matrix form to conserve space. Our objectives in this study are to describe the riparian community of ZNP floristically and environmentally and to summarize relevant information concerning prevalent species characterisitcs that have value for management and for interpreting this plant community to visitors to the Park. Plant nomenclature follows Welsh and others (1987).

VEGETATION

The prevalent species list shows boxelder maple (*Acer negundo*) to be the commonest species encountered in the 19 stands sampled in the riparian zone (table 1). Other common trees include Dixie ash (*Fraxinus velutina*) and Fremont cottonwood (*Populus fremontii*). Important small trees include bigtooth maple (*Acer grandidentatum* and Gambel oak (*Quercus gambelii*). The introduced, weedy bromes (*B. tectorum* and *B. diandrus*) that hold prominent places on the prevalent species list are tenacious reminders

of the decades of abusive grazing in the main canyon bottom prior to establishment of ZNP and exclusion of domestic grazers in 1916 (Woodbury 1933). Kentucky bluegrass (*Poa pratensis*) is also a persistent introduction in the riparian zone. All other prevalent species are natives. About 40 percent of the sum presence of prevalent species is contributed by species considered to be climax in this community type.

Three woody species were locally abundant along streams in the Park, but were not encountered in the plots sampled in the study. Those species are *Cornus sericea*, *Rosa woodsii*, and *Vitis arizonica*. All three species produce flesh fruits, which are eaten and dispersed by facultatively frugivorous birds that occur in this community.

Several rare plants are associated with the riparian areas of ZNP; for example, *Aquilegia formosa*, *Erigeron religiosus*, *E. sionis*, *Jamesia americana*, *Lupinus latifolius*, *Penstemon humilus* var. *obtusifolius*, and *Sphaeromeria ruthiae* (McArthur and others 1989; Welsh 1989). Populations of these plants seem to be healthy, albeit restricted, under current ZNP management practices.

Webb and Brotherson (1988) recognized Fremont cottonwood and Dixie ash as prevalent species in their study. They found boxelder maple to be an important species at Ash Creek, but since that species was uncommon at Leeds and Santa Clara, its overall abundance was too small to be

added to the prevalent species list for Washington County. They also found seven shrubs to be abundant enough to be listed as prevalent. Apparently, higher elevation sites in deeply shaded canyons in our study were less conducive to good performance of the shrubs, since only two shrubs (bigtooth maple and Gambel oak) appear on the prevalent species list in this study and both are large shrubs or small trees.

Rushforth and others (1982) show that the riparian trees support a variety of lichen species on their bark. For the most part, those lichen species occur only on trees. Fremont cottonwood supported the most diverse assemblage of lichens, but boxelder stems also support a rich diversity of lichens. Over a dozen lichen species are common on tree bark in the Park.

The riparian community is rather distinctive in the Park with 64 percent of the prevalent species achieving their maximum abundance (are modal) in that community. Due to site-to-site variation in recency of natural disturbance in the riparian zone (for example, flood damage to the stream course or floodplain), steepness of banks adjacent to the stream, and the degree of topographic shading (table 2), this community type is compositionally variable from one place to another (index of homogeneity of 57 percent, table 2).

Structurally, this community usually has a discontinuous tree overstory at maturity (18 percent cover) and a rather well-developed herbaceous and nonvascular plant understory cover (about 24 percent and 14 percent, respectively) (table 2). Shrubs are relatively unimportant (only two on the prevalent species list) in late-seral stages of this community, probably because of intolerance to overstory shading. Only the introduced brome grasses are annuals among the prevalents of this community. Two native species on the list (*Phacelia heterophylla* and *Thelypodium laxiflorum*) are biennials or short-lived perennials. All other native species are perennial (table 1). Where rock is abundant under the riparian canopy, saxicolous lichens are abundant. Bryophytes are found where soil occurs on shaded slopes that do not accumulate litter.

In common with riparian communities throughout the temperate zones of the world, the prevalent species of the riparian community of ZNP are overwhelmingly deciduous

Table 2—General environmental and vegetational characteristics of the riparian stands sampled in Zion National Park based on 19 macroplots. Each average value is followed by its standard error. Site elevation, solar radiation, topographic shading, parent material, and vegetational values are computed over 19 plots; soil parameters are based on a sample size of three. Potential solar beam radiation was taken from tables by Frank and Lee (1966)

Characteristic	Average value
Elevation (m)	1,500 ± 62.5
Direct solar beam radiation/yr (potential langleys/cm^2)	[1]248,100
Topographic shading index[2]	2.2 ± 0.10
Parent material	alluvium
Soil parameters	
Textural class	Loamy sand
Sand (percent)	80.6 ± 3.3
Silt (percent)	11.2 ± 1.7
Clay (percent)	8.2 ± 1.8
pH	8.0 ± 0.1
Electrical conductivity (mmhos x10^3)	2.73 ± 0.60
Available P (ppm)	4.8 ± 0.50
Exchangeable cations	
Ca (ppm)	4,208.0 ± 812
Mg (ppm)	233.6 ± 71
K (ppm)	93.0 ± 53.7
Na (ppm)	117.6 ± 66.1
Zn (ppm)	0.2 ± 0.01
Fe (ppm)	3.3 ± 0.18
Mn (ppm)	5.3 ± 1.79
Cu (ppm)	0.4 ± 0.12
Index of vegetational distinctiveness (percent)	62
Index of vegetational homogeneity (percent)	57
Vegetational living cover (percent)	68 ± 6.1
Bare soil (percent)	10 ± 2.1
Rock cover (percent)	6 ± 2.2
Litter cover (percent)	16 ± 2.5
Vegetational composition (percent of total living cover)	
Trees (percent)	26.2 ± 7.2
Shrubs (percent)	18.1 ± 5.2
Herbs (percent)	35.6 ± 6.8
Cryptogams (percent)	19.8 ± 6.7

[1]The langley is an expression of energy given in kgcal/cm^2.
[2]This index is an estimation of shading on a site from surrounding canyon walls: 1 = brief, 2 = moderate, 3 = prolonged (over 4 h/day).

in the nongrowing season (table 1). As suggested by Stebbins (1975), that relationship is probably a consequence of the fact that the alluvial soils are usually rich in the biogenic nutrients. Thus, species adapted to such environments are rarely faced with nutrient shortages and need not economize by retaining the foliage with its abundance of essential nutrients for long periods. In contrast, competition for space in the riparian zone is usually keen and success in the struggle for space is favored by deciduous leaves, which are known to be more efficient photosynthetically (Mooney and Gulmon 1982) than evergreen leaves. In addition, snow rarely falls in this community type during the growing season when the large leaves and diffuse branching habits of the dominant trees would likely result in much breakage under a heavy burden of snow. Accordingly, natural selection appears to have favored species with thin, deciduous leaves that provide the abundant supply of photosynthate required for rapid growth. Since the likelihood of nutrient deficiencies developing in the riparian zone is slight, the high annual demand for nutrients, which must be satisfied within a few weeks as each new crop of leaves expands, can be satisfied. Thus, nutrient availability has not been a deterrent for deciduous-leaved species in this community.

Mode of pollination among the prevalent flowering plants of this community is about equally divided between wind and animal vectors (table 3). As observed by Ostler and Harper (1978) in the plant communities of northern Utah, the overstory species (the trees) are wind pollinated, while the understory species are primarily animal pollinated.

At least three of the grass species (*Bromus diandrus, B. tectorum,* and *Poa pratensis*) on the prevalent list are descended from wind-pollination stock that appear to avoid the dilemma of relying on wind as the primary pollen vector by resorting, at least partially, to self pollination or apomixis (Brittingham 1943; Young and others 1987; our field observations of *B. diandrus*). That retreat from wind pollination has apparently been driven by life styles in which these aggressive weeds are regularly introduced into new environments where stray individual plants represent the norm for population density. In such situations, random undirected dispersal of pollen, as is the rule for wind-pollinated taxa, probably is an ineffective mechanism for bringing about fertilization of gametes. Mutations that resulted in selfing or apomixis were apparently at a selective advantage in such circumstances. Selfing and apomixis would continue to be desirable traits for otherwise wind-pollinated taxa growing in forest understory situations where wind movement is much reduced (Ostler and Harper 1978).

Only two nonseed plant species (*Equisetum hyemale* and *Cystopteris fragilis*) are included on the prevalent species list (table 1). Nonvascular plants (primarily mosses) cover about 15 percent of the soil surface.

In respect to topographic shading, this community is protected from direct solar beam radiation to a greater extent than any other in the Park with the single exception of the hanging gardens. Soils supporting the community are derived from cobbly alluvial deposits and are most commonly of loamy sand texture (table 2).

Table 3—Floral and reproductive characteristics of prevalent species of the riparian community sampled in Zion National Park. Species arranged in order of decreasing abundance

Species	Vegetative reproduction	Floral structure[1]	Pollinator and floral access[2]	Floral color[3]	Breeding system[4]
Acer negundo	Sprouts	A,R	W,—	—	D
Poa fendleriana	No	A,B	W,—	—	P
Bromus tectorum	No	A,B	S,—	—	P
Artemisia ludoviciana	Short rhizomes	SP,R	W?,—	Y	P
B. diandrus	No	A,B	S or W,—	—	P
Quercus gambelii	Sprouts	A,R	W,—	—	M
Acer grandidentatum	Often sprouts	A,R	W,—	—	P,M,D
B. ciliatus	No	A,B	W,—	—	P
Senecio spartioides	Short rhizomes	SP,R	I,SO	Y	P
Heterotheca villosa	No	SP,R&B	I,SO	Y	P
Fraxinus velutina	Often sprouts	A,R	W,—	—	M
Stephanomeria tenuifolia	No	SP,B	I,SO	Pi	P
Populus fremontii	May sprout	A,R	W,—	—	D
Arabis perennans	No	PP,R	I,SO	P,Pi	P
Equisetum hymale	Rhizomes	—	—	—	—
Penstemon rostriflorus	No	SP,B	B,R	R	P
Phacelia heterophylla	No	SP,R	I,R	P	P
Eriogonum racemosum	No	SP,R	I,SO	W,Pi	P
Solidago sparsiflorus	Short rhizomes	SP,R	I,SO	Y	P
Cirsium arizonicum	No	SP,R	I or B,R	R	P
Zauschneria latifolia	No	SP,B	B,R	R	P
Poa pratensis	Rhizomes	A,B	S,—	—	P
Thelypodium laxiflorum	No	PP,R	I,SO	W,P	P
Taraxacum officinale	Root sprouts	SP,B	S or I,SO	Y	P
Cystopteris fragilis	Short rhizomes	—	—	—	—

[1]A = apetalous, PP = polypetalous, SP = sympetalous, R = radial symmetry, B = bilateral symmetry.
[2]B = bird, I = insect, S = selfed or apomictic, W = wind, O = open to any pollinator, SO = semiopen (tube <5 mm long), R = restricted access (tube >5 mm long).
[3]P = purple, Pi = pink, R = red, W = white, Y = yellow.
[4]D = dioecious, M = monoecious, P = perfect.

The soils are basic in reaction (pH about 8.0) and often locally saline with electrical conductivity values ranging from near 0 to as high as 5.7 mmhos/cm. The riparian soils contain somewhat more exchangeable calcium, sodium, iron, manganese, and copper than average soils in ZNP and less potassium and zinc than average (table 2).

Most of the prevalent species are perfect flowered (table 3), but the two most common species are dioecious, and four other species (all large shrubs or small trees) are monoecious. About 30 percent of the species occurrences in the study represent species that are either dioecious or monoecious, sexual states that are known to minimize self pollination. Freeman and others (1980) observed a similar high representation of dioecious or monoecious species in the riparian communities of northern Utah. The heavy representation of nonperfect flowered species in the riparian zone may reflect a higher than average incidence of fungal, bacterial, or viral diseases among plants of the riparian zone where abundant water and reduced exposure to direct sunlight result in leaves that have thinner cuticular layers and are more easily pentrated by pathogens. Greater genetic diversity among individuals is a natural consequence of outcrossing and may reduce the likelihood that any given individual will be damaged by a particular pathogen population. It should also be noted that all the dioecious and monoecious taxa considered here are wind pollinated (table 3), another reproductive trait known to foster genetic heterogeneity within a population (Cox 1991). Even among the insect-pollinated taxa that are prevalent in this community, most are pollinated by large animals (bumblebees or hummingbirds) that travel long distances and can be expected to enhance genetic diversity in the population of plants of concern (table 3).

Yellow and red or pink flowers dominate the floral display in this community. The vast majority of the seed plants in this vegetational type reproduce by seed primarily. Only *Artemisia ludoviciana*, *Quercus gambelii*, and *Poa pratensis* reproduce vigorously vegetatively. Both nonseed, vascular plants (*Equisetum* and *Cystopteris*) also reproduce vegetatively (table 3). Several trees (*Acer negundo*, *A. grandidentatum*, *Fraxinus velutina*, and *Populus fremontii*) may sprout from the base if broken off in floods or by beaver or if burned during a wildfire. Sprouting after fire among these species is dependent upon tree age (younger stems sprout more freely) and intensity of the fire (severe burns destroy the sprouting response).

The riparian community harbors more large-leaved species than any other in the Park (table 4). This fact no doubt has its origin in the abundant supply of available water and the sharply reduced amount of direct sunlight due to topographic shading. Leaves are prevailingly simple, entire margined, and mostly glabrous or sparsely pubescent. The photosynthetic lamina are almost universally thin and flexible (table 4).

Plant fruits of prevalents in this community are dry without exception and primarily one seeded and indehiscent. Common fruit types are achenes, caryopses, and samaras. Wind is the primary means of dispersing fruits away from the parent plant, but several species apparently rely on wandering mammals to move the propagules about either as barbed bodies that catch in the fur, hair, or wool, or as seeds that retain viability after passing through an animal's digestive tract (table 5).

The riparian zone has been used by humans as a source for animal forage, sugar (maple syrup from both boxelder and bigtooth maple), fuel, and recreation. Birds use this zone heavily for both nesting and foraging. Both ungulate and small mammals also utilize this zone heavily (table 6).

None of the prevalent species of the riparian zone is likely to pose a poison threat in the Park. Gambel oak is known to produce high levels of tannins in foliage, catkins, and acorns, but they usually do not cause serious problems for the forager unless oak tissue constitutes the bulk of the diet. Primitive peoples ate acorns, but the crushed acorn tissue was washed prior to consumption to remove toxins (Harper and others 1985). *Senecio* species produce pyrolizidine alkaloids, which are powerful liver toxins that cause irreversible and progressive damage even at low dosages (Keeler 1983). The toxic properties of *Equisetum* are unlikely to damage either man or grazing animals, because the plant's epidermis is so heavily silicified that it resembles sandpaper more than anything else. Housewives of the frontier collected the stems for use as kitchen scouring pads. None of the prevalents are strong allergens and none fix nitrogen. As one might expect in this arid region where any accumulation of fuel will eventually be ignited by natural or human-related causes, many of the riparian prevalents have been selected for the ability to sprout after wildfire (table 7).

Early seral stages in this type are initiated as streams naturally erode banks and expose new sandbars or accreting shores on the edges of bends in the stream channel. Our sample includes seven macroplots classified by workers as early successional, three in midseral stage, and nine macroplots considered to be in late seral condition (table 8).

The data suggest that any one macroplot will usually contain only one or two tree species in any stage of community succession. The number of shrub and forb species increases considerably across the successional sequence considered, and grass species show an equally strong decline in numbers across that gradient (table 8).

Living plant cover tends to increase slightly from early to late-seral situations, but even newly exposed banks quickly develop a heavy vegetative cover. Tree cover becomes a progressively larger portion of the total plant cover as the community moves from early to late-seral conditions. Relative cover of shrubs shows no consistent trend across the gradient of succession. Herb cover decreases strongly and cryptogamic cover (moss and liverworts primarily) increases with equal strength as sites progress from pioneer to climax conditions.

Although the average number of tree species per macroplot remains quite constant at about two across the successional sequence, the composition of the tree community changes dramatically. Pioneer stands usually are dominated in canopy cover by Fremont cottonwood, a tree whose seeds are produced in copious quantities and are dispersed easily to great distances by wind. The few midseral sites considered here show boxelder maple, Dixie ash, and Fremont cottonwood to be about equally important in canopy coverage (table 8). Near-climax sites have boxelder maple as the major tree dominant in ZNP. Apparently, large seeds and shade tolerance in the seedling stage (characteristics of boxelder, Dixie ash, Rocky Mountain juniper, and white fir) place trees at an advantage in later seral stages (table 8).

Among the shrub species encountered in the 19 survey plots (31 shrub species observed in the plots), 18 species

Table 4—Leaf characteristics of prevalent species in a riparian community sampled in Zion National Park

Species	Leaf size class[1]	Leaf complexity[2]	Leaf texture[3]	Leaf surface[4]	Leaf margin[5]
Acer negundo	Me	C	T	LP	S
Poa fendleriana	Le	S	T	G	E
Bromus tectorum	Le	S	T	LP	E
Artemisia ludoviciana	Na	S	T	SP	E
B. diandrus	Le	S	T	MP	E
Quercus gambelii	Mi	S(L)	T	LP	E
Acer grandidentatum	Mi	S	T	LP	E
B. ciliatus	Na	S	T	MP	E
Senecio spartioides	Na	S	T	G	E
Heterotheca villosa	Le	S	T	SP	E
Fraxinus velutina	Me	C	T	LP	S
Stephanomeria tenuifolia	Le	S(L)	T	G	E
Populus fremontii	Mi	S	T	G	C
Arabis perennans	Le	S	T	SP	S
Equisetum hyemale	Ap	S	C	G	E
Penstemon rostriflorus	Le	S	T	G	E
Phacelia heterophylla	Na	S,C	T	SP	E
Eriogonum racemosum	Na	S	T	SP	E
Solidago sparsiflora	Na	S	T	LP	E
Cirsium arizonicum	Mi	S(L)	T	SP	SP
Zauschneria latifolia	Na	S	T	LP	S
Poa pratensis	Le	S	T	G	E
Thelypodium laxiflorum	Mi	S(L)	T	G	E
Taraxacum officinale	Mi	S(L)	T	LP	L
Cystopteris fragilis	Mi	C	T	G	E

[1]Ap = nonfunctional tiny leaf, Le = leptophyll (0.25-2.25 cm² area), Me = mesophyll (>182 cm² area), Mi = microphyll (20-182 cm² area), Na = nanophyll (2.30-20 cm² area).
[2]C = compound pinnate leaf, L = lobed margin, S = simple leaf.
[3]C = coriaceous or leathery, T = thin, deciduous.
[4]G = glabrous, LP = light pubescence, MP = moderate pubescence, SP = strongly pubescent.
[5]C = crenate, E = entire, L = laciniate, S = serrate, Sp = spinose.

Table 5—Characteristics of the fruits of species prevalent in the riparian communities of Zion National Park. Species arranged in decreasing order of abundance

Species	Texture and dehiscence[1]	Dispersal agent[2]	Seed per fruit
Acer negundo	D,Id	W,G	1
Poa fendleriana	D,Id	W,G	1
Bromus tectorum	D,Id	W,G,M	1
Artemisia ludoviciana	D,Id	W,G	1
B. diandrus	D,Id	W,G,M	1
Quercus gambelii	D,Id	G,M,B	1
Acer grandidentatum	D,Id	W,G	1
B. ciliatus	D,Id	W,G	1
Senecio spartioides	D,Id	W,G	1
Heterotheca villosa	D,Id	W,G	1
Fraxinus velutina	D,Id	W,G	1
Sphaeromeria tenuifolia	D,Id	W,G	1
Populus fremontii	D,De	W,G	>25
Arabis perennans	D,De	G,I	8-15
Equisetum hyemale	—	—	—
Penstemon rostriflorus	D,De	G,I	10-30
Phacelia heterophylla	D,De	G,M	2
Eriogonum racemosum	D,Id	W,G,M	1
Solidago sparsifolia	D,Id	W,G	1
Cirsium arizonicum	D,Id	W,G	1
Zauschneria latifolia	D,De	G	>10
Poa pratensis	D,Id	W,G	1
Thelypodium laxiflorum	D,De	G,I	8-15
Taraxacum officinale	D,Id	W,G	1
Cystopteris fragilis	—	—	—

[1]D = dry, De = dehiscent, Id = indehiscent.
[2]B = birds, G = gravity, I = insects (ants), M = mammals (granivorous rodents), W = wind.

Table 6—Uses of various prevalents by wild birds, small mammals, ungulate mammals, and humans in a Zion National Park riparian community

Species	Uses for birds[1]	Uses for wild mammals[2]	Uses for ungulate mammals[3]	Uses for humans[4]
Acer negundo	Sh,N,Fo	Sh		Fu,Su
Poa fendleriana		GF	GF	
Bromus tectorum	GF,Sd	GF,Sd	GF	
Artemisia ludoviciana				
B. diandrus	GF,Sd	GF,Sd	GF	
Quercus gambelii	Sd,SH,N,Fo	Sd,Sh	GF,Sd,Sh	Fu,Sd
Acer grandidentatum	Sh,N,Fo	Sh	Sh	Fu,Su
B. ciliatus	Sd	Sd	GF	
Senecio spartioides				
Heterotheca villosa				
Fraxinus velutina	Sh,N,Fo	Sh	Sh	Fu
Stephanomeria tenuifolia			GF	
Populus fremontii	Sh,N,Fo	Sh	Sh	Fu,Fi
Arabis perennans			GF	
Equisetum hyemale				Sc
Penstemon rostriflorus				
Phacelia heterophylla		Sd		
Eriogonum racemosum	Sd	Sd		
Solidago sparsiflora				
Cirsium arizonicum	Sd			
Zauschneria latifolia		Sh		
Poa pratensis		GF	GF	
Thelypodium laxiflorum			GF	
Taraxacum officinale		GF	GF	GF
Cystopteris fragilis				

[1]Fo = foraging place, GF = green food, N = nesting site, Sd = seed food, Sh = shelter.
[2]GF = green food, Sd = seed food, Sh = shelter.
[3]GF = green food, Sd = seed food, Sh = shelter.
[4]Fi = fiber, Fu = fuel, GF = green food, Sc = scouring pads, Sd = seeds for food, Su = sugar.

Table 7—Some important desirable and undesirable characteristics of prevalent species of the Zion National Park riparian community

Species	Nitrogen fixer	Response to wildfire	Allergenic properties	Poisonous qualities
Acer negundo	No	Sometimes sprouts[1]	None[2]	
Poa fendleriana	No	Usually survives	None	
Bromus tectorum	No	Increases	None	
Artemisia ludoviciana	No	May increase	None	
B. diandrus	No	May increase	None	
Quercus gambelii	No	Sprouts vigorously	None	Tannins (Harper and others 1985, 1988)
Acer grandidentatum	No	Sometimes sprouts	None	
B. ciliatus	No	?	None	
Senecio spartioides	No	Survives	None	Pyrrolizidine alkaloids
Heterotheca villosa	No	Survives	None	(Brotherson and others 1980; Jeppsen 1985)
Fraxinus velutina	No	?	None	
Stephanomeria tenuifolia	No	?	None	
Populus fremontii	No	Sometimes sprouts	None	
Arabis perennans	No	Survives	None	
Equisetum hyemale	No	Survives	None	Thiaminase alkaloid (Fuller and McClintock 1986)
Penstemon rostriflorus	No	?	None	
Phacelia heterophylla	No	?	None	
Eriogonum racemosum	No	Survives	None	
Solidago sparsiflora	No	Survives	None	
Cirsium arizonicum	No	?	None	
Zauschneria latifolia	No	Survives	None	
Poa pratensis	No	Survives	None	
Thelypodium laxiflorum	No	?	None	
Taraxacum officinale	No	Survives	None	
Cystopteris fragilis	No	?	None	

[1]Species noted as sometimes sprouting are most likely to sprout from young stems growing on moist sites where high moisture percentages in fuel result in light burns.
[2]None known.

Table 8—Successional trends in the Zion National Park riparian stands sampled in this study

Characteristic	Successional stage		
	Early	Mid-seral	Near climax
No. macroplots	7	3	9
Avg. No. tree species	1.7	1.0	2.0
Avg. No. shrub species	2.3	3.0	5.2
Avg. No. graminoid species	6.4	7.7	3.1
Avg. No. forb species	7.4	8.0	15.6
Avg. total vascular species	17.8	19.7	25.9
Avg. total living plant cover (percent)	64.1	66.8	71.4
Composition of living cover (percent contribution by each life form group)			
Trees	19.3	21.4	29.9
Shrubs	20.1	5.1	22.6
Herbs	60.7	45.5	16.7
Cryptogams	0	28.1	30.9
Dominant tree species	*Populus fremontii*	*Acer negundo* *Fraxinus velutina* *Populus fremontii* (all about equally dominant)	*Acer negundo*
Percentage of plots with the tree			
Abies concolor	0	0	33
Acer negundo	42	33	89
Celtis reticulata	14	0	0
Fraxinus velutina	42	33	22
Juniperus scopulorum	0	0	11
Pinus monophylla	0	0	11
Pinus ponderosa	0	0	11
Populus fremontii	71	33	0
Pseudotsuga menziesii	0	0	22
Percentage of plots with the shrub			
Acer glabrum	0	0	22
A. grandidentatum	0	0	78
Artemisia filifolia	0	33	0
A. tridentata	28	0	0
Baccharis emoryi	28	0	0
Chrysothamnus nauseosus	28	33	0
Gutierrezia sarothrae	28	66	0
Holodiscus dumosus	0	0	33
Jamesia americana	0	0	22
Mahonia repens	0	0	33
Opuntia macrorhiza	0	66	11
Pachystima myrsinites	0	0	22
Philadelphus microphyllus	0	0	33
Quercus gambelii	28	0	67
Salix exigua	42	0	0
Salix scouleriana	0	0	22
Symphoricarpos oreophilus	0	0	22
Tamarix ramosissima	42	33	0

occurred more than once (table 8). Smooth maple (*Acer glabrum*) and bigtooth maple (*A. grandidentatum*) increased strongly in late-seral stages. Both are known to have large seeds and to be shade tolerant. Snowberry (*Symphoricarpos oreophilus*) also increased in near-climax stands on cool sites. Other species most common in late-seral situations include *Holodiscus dumosus*, *Jamesia americana*, and *Philadelphus microphyllus*, all species adapted to the rock outcrops that border the riparian strip in the narrow canyons of ZNP. *Salix scouleriana, Quercus gambelii, Pachystima myrsinites*, and *Mahonia repens* are also uncommon in early seral situations. The former two species are only moderately shade tolerant and cling to better lighted edges of the riparian strip. The latter two species are evergreen, moderately shade tolerant, and apparently strongly mycorrhizal.

Those characteristics are shared by many species of moderately dark, understory situations where there is abundant organic matter on and in the surface soil.

The composite shrub species (*Artemisia, Chrysothamnus, Gutierrezia*, and *Baccharis*) all play early seral roles in the riparian zone in the Park (table 8). Two small shrubs with tiny, wind-dispersed seeds are common pioneering species on disturbed riparian edges and gravel bars; sandbar willow (*Salix exigua*) is a native, and tamarix (*Tamarix ramosissima*) is an aggressive introduced weed. Fortunately, tamarix is not shade tolerant and is small enough to be suppressed as the canopy of trees closes above. In many situations where stream channels are regularly and severely reworked by flood waters, the stream channel is exposed to full sun, and water flow is intermittent in at least some years, tamarix

displaces native shrubs and forms essentially monotypic stands. Such stands are little used by such common mammal denizens of riparian strips as mule deer and beaver. It has been reported that tamarix stands also support an impoverished avian fauna relative to the native, displaced shrubs (Brotherson and Field 1987).

ANIMALS

Our study did not collect data on animals of the riparian communities of the Park, but for sake of completeness we will review briefly important animal features of those communities and make reference to recent studies of animal relations in other southwestern riparian systems. As noted earlier, animals have been studied in the riparian zone of ZNP since its establishment. The one animal known to be endemic to the Park is the Zion snail (*Petrophysa zionis* Pilsbey) (Chamberlin and Jones 1929). This small creature (only 4.5 mm long and 3.6 mm in diameter) lives only on the dripping faces of sandstone cliffs, where it feeds on the thick algal mats supported by water seeping from the porous rock. It is known from only a few locations in the main canyon near the entrance to the Virgin River Narrows near the Temple of Sinawava. It is possible that populations of the rare and endangered Virgin River chub (*Gila robusta seminuda*) exist in the North Fork of Virgin River within the Park (Shiozawa 1991; Woodbury 1933). The woundfin minnow (*Plagopterus argentissimus* Cope), another endangered fish of southwestern Utah, is not known to have occurred within ZNP (Shiozawa 1991). The Virgin River spindace (*Lepidomeda mollispinis mollispinis*), a species being considered for listing as threatened, is common in ZNP.

Woodbury (1933) lists numerous insect species in the orders Diptera, Ephemeroptera, Odanata, Plecoptera, and Trichoptera that depend on streams and pools for suitable habitat during a portion of their life cycles. Recent studies of the avian species associated with riparian environments in desert regions (Szaro and Jakle 1985) in Arizona underscore the importance of such habitats for that group of animals. They found that wooded riparian strips supported three to four times as many individual birds as adjacent washes that carried water only occasionally each year. Upland desert scrub communities also had far fewer birds than riparian strips. The average number of bird species per 40-ha (98.8-acre) plot in those three environments differed less than did the number of individuals. There were slightly more species in desert wash habitats than in the riparian strip, but about 25 percent of the avian species of washes achieved maximum abundance in the riparian strip. They considered that only about 20 percent of the riparian zone birds (of about 24 species) were year-round residents. Those year-round species were joined by two or three migrant species each winter in the Arizona study. In contrast, desert wash and desert scrub communities had about one-third of their species remain year-round. Brotherson and Field (1987) conclude that displacement of native trees and shrubs by *Tamarix ramosissima* will reduce avian species richness in the riparian zone.

Szaro and Belfit (1987) investigated the relative species richness and animal density of small mammals in riparian, desert wash, and desert scrub communities at the same site used by Szaro and Jakle (1985) for bird studies in central Arizona. They found that small mammal species were about equally numerous on 0.07-ha (0.17-acre) sample plots in the three communities (two to four species), but rodent density in the riparian strip was less than half that of desert scrub uplands and only one-sixth that found in desert washes.

Land managers working in the Great Basin section of southeastern Oregon concluded that "riparian zones are the most critical wildlife habitats in managed rangelands" (Thomas and others 1979). They considered that roads within the riparian zone have severe, adverse effects on the quality of that habitat for all forms of wildlife. Since roads so often parallel streams in ZNP, their construction and management should be a major concern.

DISEASES

In 1988, the ash yellows disease was discovered in *Fraxinus velutina* trees in the main canyon of the North Fork of the Virgin River in ZNP (Sinclair and others 1991). Since the pathogenic cause of ash yellows, a mycoplasm-like organism, was isolated from ash twigs from ZNP by those familiar with the disease in Eastern United States, there is little doubt that the disease is present in the Park. Although the number of trees now showing symptoms in the Park is small, there is cause for serious concern, since the disease is spread readily by a variety of plant-feeding insects and usually kills infected trees. Inasmuch as ash is an important tree species in all seral stages of the riparian communities of ZNP (see table 8), significant changes can be expected in the Park's riparian zone if the disease is not controlled before it reaches epidemic proportions.

ACKNOWLEDGMENTS

REFERENCES

Behle, W. H. 1943. Birds of the Pine Valley Mountain region, southwestern Utah. University of Utah Biological Series. 7(5): 1-85.

Braun-Blanquet, J. 1927. Plant sociology: the study of plant communities. Translated from German by Fuller, G. D., and Conard, H. S. New York: McGraw-Hill. 439 p.

Brittingham, W. H. 1943. Type of seed formation as indicated by the nature and extent of variation in Kentucky bluegrass and its practical applications. Journal of Agricultural Research. 67: 225-264.

Brotherson, J. D.; Field, D. 1987. Tamarix: impacts of a successful weed. Rangelands. 9: 110-112.

Brotherson, J. D.; Szyska, L. A.; Evenson, W. E. 1980. Poisonous plants of Utah. Great Basin Naturalist. 40: 229-253.

Chamberlin, R. V.; Jones, D. T. 1929. A descriptive catalog of the Mollusca of Utah. University of Utah Biological Series. 1(1): 1-203.

Cox, P. A. 1991. Abiotic pollination: an evolutionary escape for animal-pollinated angiosperms. London: Philosophical Transactions of the Royal Society. B333: 217-224.

Curtis, J. T. 1959. The vegetation of Wisconsin: an ordination of plant communities. Madison, WI: The University of Wisconsin Press. 657 p.

Eubank, M.; Brough, R. C. 1979. Utah weather. Bountiful, UT: Horizon Publishers and Distributors. 284 p.

Frank, E. C.; Lee, R. 1966. Potential solar beam irradiation on slopes—tables for 30° to 50° latitude. Res. Pap. RM-18. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 116 p.

Freeman, D. C.; Harper, K. T.; Ostler, W. K. 1980. Ecology of plant dioecy in the Intermountain Region of western North America and California. Oecologia. 44: 410-417.

Fuller, T. C.; McClintock, E. 1986. Poisonous plants of California. Berkeley, CA: University of California Press. 435 p.

Harper, K. T.; Ruyle, G. B.; Rittenhouse, L. R. 1988. Toxicity problems associated with the grazing of oak in intermountain and southwestern U.S.A. In: James, L. F.; Ralphs, M. H.; Nielsen, D. B., eds. The ecology and economic impact of poisonous plants on livestock production. Boulder, CO: Westview Press: 197-206.

Harper, K. T.; Sanderson, S. C.; McArthur, E. D. 1988. Vegetative communities of Zion National Park. In: University of Wyoming National Park Service Research Center, Eleventh Annual Report, 1987. Laramie, WY: University of Wyoming: 191-196.

Harper, K. T.; Sanderson, S. C.; McArthur, E. D. 1990. Vegetative communities of Zion National Park. In: University of Wyoming National Park Service Research Center, Thirteenth Annual Report, 1989. Laramie, WY: University of Wyoming: 234-240.

Harper, K. T.; Sanderson, S. C.; McArthur, E. D.; Tuhy, J. S. 1989. Vegetative communities of Zion National Park. In: University of Wyoming National Park Service Research Center, Twelfth Annual Report, 1988. Laramie, WY: University of Wyoming: 207-214.

Harper, K. T.; Wagstaff, F. J.; Kunzler, L. M. 1985. Biology and management of the Gambel oak vegetative type: a literature review. Gen. Tech. Rep. INT-179. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 31 p.

Jeppsen, R. B. 1985. The contribution of pyrrolizidine alkaloids to the taxonomy of *Senecio* L. species in Utah. Provo, UT: Brigham Young University, Department of Botany and Range Science. 79 p. Dissertation.

Keeler, R. F. 1983. Plant metabolites that are teratogenic in offspring and toxic in the dam. Toxicon (supplement 3): 221-225.

McArthur, E. D.; Sanderson, S. C.; Harper, K. T. 1989. Expansion of the known distribution of the rare Zion tansy, *Sphaeromeria ruthiae* (Asteraceae). Southwestern Naturalist. 34: 441-443.

Mooney, H. A.; Gulmon, S. L. 1982. Constraints on leaf structure and function in reference to herbivory. Bioscience. 32: 198-201, 204-206.

Ostler, W. K.; Harper, K. T. 1978. Floral ecology in relation to plant species diversity in the Wasatch Mountains of Utah and Idaho. Ecology. 50: 848-861.

Padgett, W.; Youngblood, A. P. 1986. Riparian community type classification of southern Utah. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region, Ecology and Classification Program. 57 p.

Padgett, W. G.; Youngblood, A. P.; Winward, A. H. 1989. Riparian community type classification of Utah and southeastern Idaho. Ecol. 89-01. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 191 p.

Rushforth, S. R.; St. Clair, L. L.; Brotherson, J. D. 1982. Lichen community structure in Zion National Park. The Bryologist. 85: 185-192.

Shiozawa, D. K. 1991. Personal communication with K. T. Harper, Brigham Young University, Provo, UT.

Sinclair, W. A.; Treshow, M.; Davis, R. E. 1991. Ash yellows in Zion National Park: impact, identity of pathogen mode of spread, and prospects for management. In: University of Wyoming National Park Service Research Center, Fourteenth Annual Report, 1990. Laramie, WY: University of Wyoming: 199-202.

Stebbins, G. L. 1975. Shrubs as centers of adaptive radiation and evolution. In: Stutz, H. C., ed. Proceedings symposium and workshop—wildland shrubs. Special Publication. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; Utah State Division of Wildlife Resources; Brigham Young University; Utah State University; Utah Section of Society for Range Management: 120-140.

Szaro, R. C.; Belfit, S. C. 1987. Small mammal use of a desert riparian island and its adjacent scrub habitat. Res. Note RM-473. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 5 p.

Szaro, R. C.; Jakle, M. P. 1985. Avian use of a desert riparian island and its adjacent scrub habitat. The Condor. 87: 511-519.

Thomas, J. W.; Maser, C.; Rodiek, J. E. 1979. Wildlife habitats in managed rangelands—the Great Basin of southeastern Oregon: riparian zones. Gen. Tech. Rep. PNW-80. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 18 p.

Webb, G. M.; Brotherson, J. D. 1988. Elevational changes in woody vegetation along three streams in Washington County, Utah. Great Basin Naturalist. 48: 512-529.

Welsh, S. L. 1989. Zion National Park threatened and endangered and exotic plant surveys (CX 1590-7-0001), final report 1988-1989. Orem, UT: Endangered Plant Studies, Inc. 164 p.

Welsh, S. L.; Atwood, N. D.; Higgins, L. C.; Goodrich, S. 1987. A Utah flora. Great Basin Naturalist Memoir No. 9. 894 p.

Woodbury, A. M. 1933. Biotic relationships of Zion Canyon, Utah with special reference to succession. Ecological Monographs. 3: 147-245.

Young, J. A.; Evans, R. A.; Eckert, R. E., Jr.; Kay, B. L. 1987. Cheatgrass. Rangelands. 9: 266-270.

245

WATER SOURCES OF PLANTS GROWING IN WOODLAND, DESERT, AND RIPARIAN COMMUNITIES: EVIDENCE FROM STABLE ISOTOPE ANALYSIS //

Lawrence B. Flanagan
James R. Ehleringer
Todd E. Dawson

ABSTRACT

The analysis of the ratio of deuterium to hydrogen in stem xylem water can be used to determine the water sources used by individual plants. This is possible because the potential water sources for plants—summer precipitation, stream water, and groundwater—often have different isotopic compositions and there is no isotopic fractionation during water uptake by plant roots. The isotopic composition of stem water, therefore, reflects the isotopic composition of water taken up by roots. Using stable isotope techniques, evaluations were made of the water sources used by co-occurring trees and shrubs in three different vegetation types: a pinyon-juniper woodland, a desert scrubland, and a riparian community. At both the woodland and desert scrubland sites, there were significant differences among species in the relative use of summer precipitation and groundwater. In addition, water-use efficiency during photosynthetic gas exchange differed among species and was strongly correlated with differences in the relative uptake of summer precipitation and groundwater at the woodland site. In the riparian community, small trees used either stream water or summer precipitation depending on their location relative to the stream. In contrast, large trees did not make use of either precipitation or stream water, but instead used subsurface groundwater regardless of their location relative to the stream.

INTRODUCTION

The use of stable isotopes in ecological research has expanded greatly in the last few years (Rundel and others 1988). For all the major elements of biological interest—carbon, hydrogen, nitrogen, and oxygen—there are at least two naturally occurring stable isotopes per element. Because of small differences in the physical and chemical properties of the isotopes of a given element, the isotopes become unevenly distributed in the environment. Measurements of the stable isotopic composition of compounds within organisms and within the abiotic environment can provide important information about physiological processes and elemental fluxes through ecosystems (Rundel and others 1988).

The primary purpose of this paper is to illustrate how measurements of the stable hydrogen isotopic composition of plant stem water can be applied in studies of the water sources used by individual plants. During water uptake by plant roots no isotopic fractionation occurs (White and others 1985). The isotopic composition of water in roots and stems reflects, therefore, the isotopic composition of water taken up by the roots. If the potential sources of water for plants—precipitation, stream water, and groundwater—have different isotopic compositions, it is possible to trace the relative uptake of the various sources by measuring the stem-water isotopic composition. Comparison of the stem-water isotopic composition with the possible source-water isotopic compositions allows a quantitative determination of the water sources used by individual plants (Flanagan and Ehleringer 1991; White 1988; White and others 1985). In this paper we describe results from studies of water-source use in three different vegetation types: a pinyon-juniper woodland, a desert scrubland, and a riparian community.

METHODS

Plant stem samples were collected in the field and immediately placed in a glass tube, which was sealed with a rubber stopper and wrapped with Parafilm. The plant samples were frozen until water was extracted from the tissue using a cryogenic vacuum distillation apparatus (Ehleringer and Osmond 1989).

Environmental water samples—precipitation, stream water, and groundwater—were collected in glass vials and sealed with a tightly sealing cap. Groundwater samples were obtained from springs at the Coral Pink State Park and Stud Horse Point sites, and from several springs and wells in and around the Red Butte Canyon site. All sites are in Utah.

Water samples were prepared for measurements of the hydrogen isotopic composition by reacting approximately 5 µL of water with zinc (Coleman and others 1982) in an

43

evacuated tube at 500 °C. The zinc was obtained from the laboratory of J. M. Hayes, Departments of Chemistry and Geology, Indiana University. The resulting hydrogen gas was analyzed for isotopic composition on either a Finnigan-Mat delta E or delta S gas isotope ratio mass spectrometer. Precision of the measurements of a laboratory standard was ±1.4‰ for the delta E and ±1.0‰ for the delta S mass spectrometers (± standard deviation).

Leaf-tissue samples were collected from four plant species at the Coral Pink State Park site. The leaf samples were collected from several different positions in the canopy, combined for an individual plant, dried, and finely ground. The carbon isotopic composition of CO_2, generated from leaf tissue in an in-vial combustion procedure (Ehleringer and Osmond 1989), was measured on the mass spectrometers described above.

Isotopic compositions are expressed using delta notation in parts per thousand (‰), $\delta D = [D/H_{Sample}/D/H_{Standard} - 1] \times 10^3$ ‰, where the standard for water samples is standard mean ocean water (SMOW) and the standard for carbon samples is Pee Dee Belemnite (PDB) limestone (Ehleringer and Osmond 1989).

Plant stem-water potential was measured with a pressure chamber (PMS Instrument Co., Corvallis, OR).

PINYON-JUNIPER WOODLAND RESULTS

The first study was a comparison of the water sources used by four co-occurring plant species in a pinyon-juniper woodland at Coral Pink Sand Dunes State Park in southern Utah. The four study species included two trees, Utah juniper (*Juniperus osteosperma*) and pinyon pine (*Pinus edulis*), and two shrubs, big sagebrush (*Artemisia tridentata*) and rabbitbrush (*Chrysothamnus nauseosus*).

At the Coral Pink study site, the hydrogen isotopic composition (δD) of precipitation varies seasonally (fig. 1), as is typical for temperate, continental locations (Dansgaard 1964). Precipitation is relatively enriched in deuterium in the summer and is relatively depleted in deuterium in the winter. In contrast, the hydrogen isotopic composition of groundwater is constant throughout the year, averaging approximately –96‰ (fig. 1). The isotopic composition of groundwater represents a weighted average of the isotopic composition of precipitation inputs, which cycle during the year. Since the two potential sources of plant water at this site, precipitation and groundwater, differ in hydrogen isotopic composition during the summer months, it is possible to determine the relative uptake of the potential sources by measuring the isotopic composition of plant stem water (Flanagan and Ehleringer 1991; White 1988).

When sampled during the main 1990 growing season, May through August, there were significant differences among species for stem-water δD values. Rabbitbrush had stem-water δD values in May, July, and August that were not significantly different from those of groundwater. In contrast, the other three species had stem-water δD values that were intermediate between the groundwater value and summer precipitation values, indicating that a mixture of both precipitation and groundwater was being used by these species. The two tree species generally had higher δD values than did big sagebrush, indicating a higher
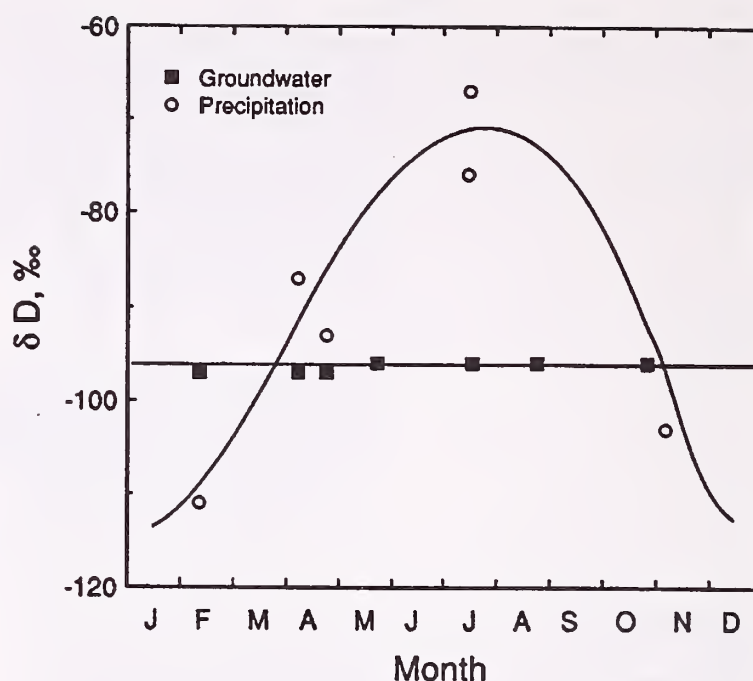
Figure 1—The hydrogen isotope composition (δD, ‰) of groundwater and precipitation at Coral Pink Sand Dunes State Park, UT, during 1990. From Flanagan and others (1991).

uptake of summer precipitation by the tree species. The data in figure 2, from stems collected in July, show the typical pattern observed for the different species in 1990, which had near-average precipitation levels (precipitation during April through August 1990 was 87.9 mm at Kanab, UT, the closest State weather station; the long-term normal for this time period is 104.6 mm).

The stem-water D/H data suggest that there were significant differences among the species compared here for the distribution of functional roots in the soil. Because soil-water content varies greatly with depth in the sandy soils at our study site (typical for Great Basin locations; Dobrowolski and others 1990), it was expected that species with different rooting patterns would have different predawn water potentials. Predawn water potential is a good indicator of the soil-water potential experienced by a plant (Ritchie and Hinckley 1975). Plants with a high proportion of active roots in the upper, dry soil horizons should have a lower predawn water potential than plants with roots predominantly in the deeper, moist soil horizons. There was a strong negative correlation between stem-water δD values and predawn water potential in July (Pearson Correlation Coefficient, $r = -0.828$, $n = 16$, $P < 0.01$, fig. 2). Similar negative correlations between stem-water δD and predawn water potential were also observed in May and August (May, $r = -0.597$, $n = 16$, $P < 0.01$; August, $r = -0.795$, $n = 16$, $P < 0.01$). Rabbitbrush had the highest predawn water potentials and stem-water D/H ratios, indicating exclusive use of groundwater (fig. 2). Big sagebrush had lower predawn water potentials and higher δD values than rabbitbrush, indicating uptake of a mixture of both recent precipitation and groundwater. These data are consistent with information from excavation studies that indicates big sagebrush has approximately the same maximum rooting depth as rabbitbrush, but a higher proportion of lateral roots,

Figure 2—The relationship between plant water potential and stem xylem water hydrogen isotopic composition (δD, ‰) and water-use efficiency calculated from leaf carbon isotope composition (Farquhar and others 1989). Values are means, $n = 4$. The error bars represent 95 percent comparison intervals calculated by the T-method after an analysis of variance (Sokal and Rohlf 1981). Means whose intervals do not overlap are significantly different ($P < 0.05$). From Flanagan and others (1991).

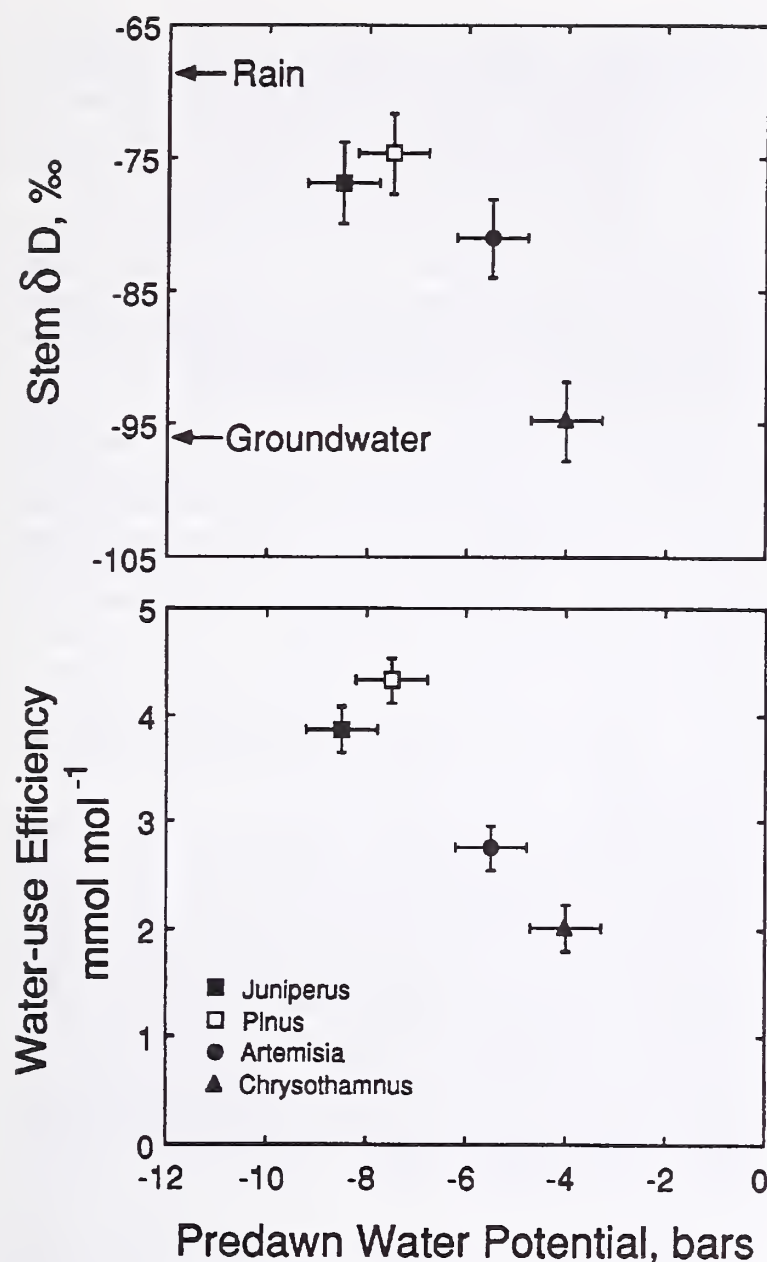particularly in the shallow soil horizons (Manning and Groeneveld 1990; Reynolds and Fraley 1989; Sturges 1977). The two tree species had even lower average predawn water potentials and higher average stem-water δD values, indicating higher average use of summer precipitation than big sagebrush (fig. 2). These data suggest that the trees have a high proportion of active roots in the shallow soil horizons, although roots of Utah juniper and pinyon may not be as responsive to small precipitation events as big sagebrush (Flanagan and others, unpublished data).

Differences in leaf gas-exchange characteristics and water-use efficiency were associated with differences in the water uptake patterns among the species (fig. 2). Leaf carbon

isotope composition was significantly different among all species, with pinyon and rabbitbrush having the highest and lowest $\delta^{13}C$ values, respectively. Assuming that the leaf-air vapor pressure difference was equivalent for all species, there was a greater than two-fold difference in water-use efficiency among the species compared (fig. 2). Calculated water-use efficiency was strongly correlated with the stem δD values for all species (May, $r = 0.900$, $n = 16$, $P < 0.01$; July, $r = 0.861$, $n = 16$, $P < 0.01$; August, $r = 0.795$, $n = 16$, $P < 0.01$). The greater the utilization of summer precipitation, a relatively unstable water source in these environments (Ehleringer and Mooney 1983), the higher the water-use efficiency (the more conservative the water use of a species; fig. 2). Rabbitbrush utilizing a stable groundwater source had the lowest water-use efficiency.

In climates where annual precipitation is less than 500 mm (much of the Great Basin; Dobrowolski and others 1990), water availability is the major factor limiting primary productivity (Ehleringer and Mooney 1983). Competition for limited water resources is an important process influencing community dynamics (Fowler 1986). The competitive ability of Great Basin plants has been related to plant-root characteristics that influence soil water-use (Dobrowolski and others 1990; Eissenstat and Caldwell 1988). The differential utilization of precipitation and groundwater shown here suggests that co-occurring trees and shrubs may not compete for the same soil-moisture resource during the summer, although the two tree species are likely to compete directly for water. The relatively high utilization of summer precipitation by the two tree species, juniper and pinyon, and their high water-use efficiency, may result in increased productivity in a climate where the proportion of summer precipitation increases, as is anticipated to occur with a doubling of global CO_2 levels (Manabe and Wetherald 1986; Mitchell 1989; Schlesinger and Mitchell 1987). Unless groundwater levels dropped significantly, rabbitbrush would be relatively unaffected by changes in the relative proportion of summer and winter precipitation.

DESERT SCRUBLAND RESULTS

The second study focused on the water sources used by the dominant species in a desert scrub community at Stud Horse Point, UT, located near Page, AZ. Summer precipitation has a δD value of approximately –25‰, while groundwater has a δD value of approximately –90‰ at this site. In this study the use of summer precipitation was found to be lifeform dependent. Annuals and a succulent perennial, *Yucca angustissima*, exhibited complete dependence on summer precipitation (fig. 3). In contrast, herbaceous and woody perennials used a mixture of precipitation and groundwater, with the herbaceous perennials more reliant on summer precipitation. There were a few deep-rooted, woody perennials that exhibited no response to summer precipitation and only used groundwater (fig. 3).

Currently precipitation in southern Utah and northern Arizona is evenly partitioned between winter and summer time periods. However, global circulation models predict that summer precipitation will increase in response to anticipated climate change (Mitchell 1989; Schlesinger and Mitchell 1987). The data in figure 3 suggest that plant species within the community will differentially respond to the anticipated change in precipitation patterns.
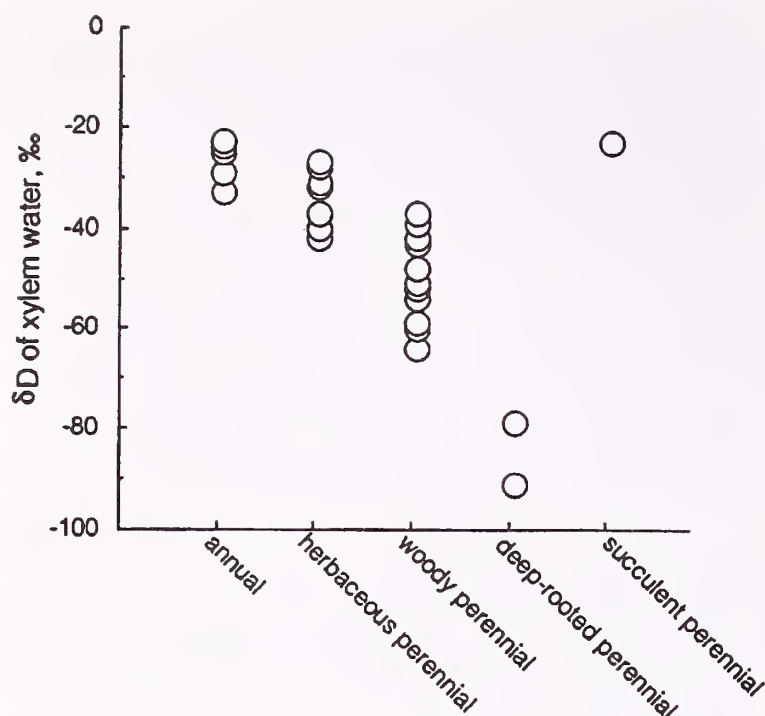
Figure 3—Hydrogen isotopic composition (δD, ‰) of stem xylem water from common plant species during the summer at Stud Horse Point, UT. The species were distinguished on the basis of lifeform. The annuals included *Ambrosia acanthicarpa, Dicoria brandegei, Helianthus anomolus, Kallstroemia californica,* and *Salsola iberica.* The herbaceous perennials included *Astragalus mollissimus, Cordylanthus wrightii, Croton californicus, Cryptantha confertiflora, Sphaeralcea grossulariifolia, Sphaeralcea parvifolia,* and *Sporobulus flexuosus.* The woody perennials included *Artemisia filifolia, Atriplex canescens, Coleogyne ramosissima, Chrysothamnus nauseosus, Chrysothamnus pulchellus, Cowania mexicana, Ephedra cutleri, Eriogonum corymbosum, Fraxinus anomala, Gutierrezia sarothrae, Oenothera pallida, Quercus undulata,* and *Vanclevea stylosa.* The succulent perennial was *Yucca angustissima.* From Ehleringer and others (1991).

RIPARIAN COMMUNITY RESULTS

The third study was conducted in Red Butte Canyon Natural Area, located directly east of Salt Lake City in the Wasatch Mountains. The study was a comparison of the water sources used by dominant trees adjacent to and distant from a perennial stream that runs through the canyon. The dominant trees along the stream are two maple species, box elder (*Acer negundo*) and big-tooth maple (*Acer grandidentatum*).

In Red Butte Canyon there are three potential sources of water for plant growth—precipitation, stream water, and subsurface groundwater. The hydrogen isotopic composition (δD) of precipitation varies throughout the growing season in the range −115‰ to −50‰. The isotopic composition of stream water remains constant throughout the year with δD values averaging −121‰. The subsurface groundwater has a δD value of −132‰.

In figure 4, stem-water δD data are plotted as a function of tree stem diameter measured at breast height (d.b.h.).

Stem samples were collected during July at the peak of the growing season in 1989. Three major conclusions can be drawn from the data in figure 4. First, for the trees smaller than 20 cm d.b.h., stem-water D/H ratios differ for a species depending on the location of the tree relative to the stream. Small trees distant from the stream have stem-water δD values enriched above that of the stream water, but in the range of summer precipitation. This indicates that precipitation is the major water source for the small trees located away from the stream (fig. 4). In contrast, small trees (less than 20 cm d.b.h.) adjacent to the stream have lower stem-water δD values that are in the range of stream water. As expected, this indicates that stream water is the major water source for small trees located adjacent to the stream. The second major point is that, for trees larger than 20 cm d.b.h., stem-water D/H ratios are not significantly different for trees growing adjacent to, or distant from, the stream. The third and most unexpected conclusion was that trees larger than 20 cm d.b.h. had stem-water D/H ratios more negative than the stream water but similar to the subsurface groundwater. The large trees, even if they were growing in or adjacent to the stream, had stem-water δD values approximately −132‰, indicating that they did not use stream water.

A diagrammatic interpretation of the data for large trees in figure 4 is shown in figure 5. If the large trees have roots distributed continuously throughout the soil profile, they would potentially have access to recent precipitation, stream water, and groundwater, which all can be distinquished by their different hydrogen isotopic compositions (fig. 5). The observed stem-water D/H ratios for the large trees, both adjacent to and distant from the stream, were approximately −132‰ (fig. 4). These data indicate that the active sites of water absorption in the large trees were limited to roots in the deep soil horizons.

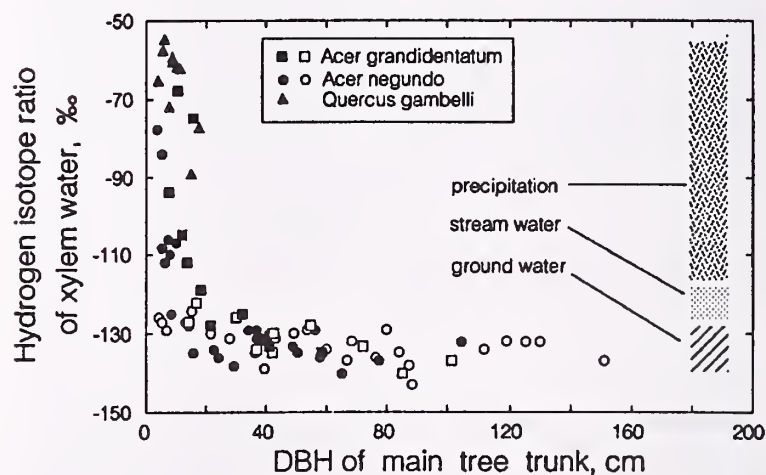**Figure 4**—Hydrogen isotopic composition (δD, ‰) of stem xylem water of three common streamside (open symbols) and adjacent nonstreamside (closed symbols) tree species in the Red Butte Canyon Research Natural Area in July 1989 as a function of the diameter at breast height (d.b.h.) of the main trunk. Mean δD values of the stream water and subsurface groundwater were −121‰ and −132‰, respectively. From Dawson and Ehleringer (1991).
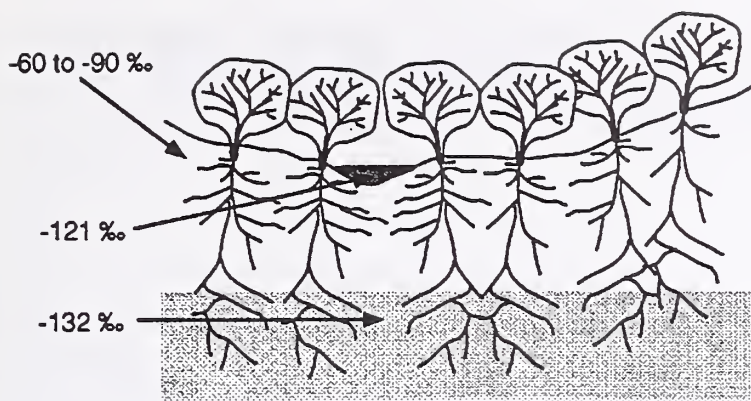
Figure 5—Representation of the rooting profiles and potential water sources of large trees in the Red Butte Canyon Natural Area. Water uptake in large trees is confined to the subsurface groundwater source, the shaded area in the diagram. From data in Dawson and Ehleringer (1991).

CONCLUSIONS

Measurements of the isotopic composition of plant stem water and environmental source waters offer great promise for ecological studies of plant water use. Data presented in this paper indicate that there may be significant differences in the water sources used for growth among co-occurring plant species. Photosynthetic water-use efficiency was correlated with differences in water-source use among species in a pinyon-juniper woodland. The differences in stem-water D/H ratios observed in our studies suggest differences in rooting pattern and belowground resource acquisition that may limit the amount of competition among co-occurring species. Knowledge of the physical distribution pattern of roots in the soil profile is not necessarily sufficient for understanding the major sites of water uptake by roots. Differential use of summer precipitation suggests a differential response among co-occurring species to shifts in the proportion of summer and winter precipitation that are anticipated to occur as a consequence of global climate change.

REFERENCES

Coleman, M. L.; Shepard, T. J.; Durham, J. J.; Rouse, J. E.; Moore, G. R. 1982. Reduction of water with zinc for hydrogen isotope analysis. Analytical Chemistry. 54: 993-995.

Dansgaard, W. 1964. Stable isotopes in precipitation. Tellus. 16: 436-468.

Dawson, T. E.; Ehleringer, J. R. 1991. Streamside trees that do not use stream water. Nature. 350: 335-337.

Dobrowolski, J. P.; Caldwell, M. M.; Richards, J. H. 1990. Basin hydrology and plant root systems. In: Osmond, C. B.; Pitelka, L. F.; Hidy, G. M., eds. Plant biology of the basin and range. Berlin: Springer-Verlag: 243-292.

Ehleringer, J. R.; Mooney, H. A. 1983. Photosynthesis and productivity of desert and Mediterranean climate plants. In: Lange, O. L.; Nobel, P. S.; Osmond, C. B.; Ziegler, H., eds. Encyclopedia of plant physiology, new series, volume 12D. Berlin: Springer-Verlag: 205-232.

Ehleringer, J. R.; Osmond, C. B. 1989. Stable isotopes. In: Pearcy, R. W.; Ehleringer, J. R.; Mooney, H. A.; Rundel,

P. W., eds. Plant physiological ecology: field methods and instrumentation. London: Chapman and Hall: 281-300.

Ehleringer, J. R.; Phillips, S. L.; Schuster, W. F. S.; Sandquist, D. R. 1991. Differential utilization of summer rains by desert plants: implications for competition and climate change. Oecologia. [In press].

Eissenstat, D. M.; Caldwell, M. M. 1988. Competitive ability is linked to rates of water extraction: a field study of two aridland tussock grasses. Oecologia. 75: 1-7.

Farquhar, G. D.; Ehleringer, J. R.; Hubick, K. T. 1989. Carbon isotope discrimination and photosynthesis. Annual Review of Plant Physiology and Plant Molecular Biology. 40: 503-537.

Flanagan, L. B.; Ehleringer, J. R. 1991. Stable isotope composition of stem and leaf water: applications to the study of plant water-use. Functional Ecology. 5: 270-277.

Flanagan, L. B.; Ehleringer, J. R.; Marshall, J. D. [In review]. Differential uptake of summer precipitation and groundwater among co-occurring trees and shrubs in the southwestern United States. Nature.

Fowler, N. 1986. The role of competition in plant communities in arid and semi-arid regions. Annual Review of Ecology and Systematics. 17: 89-110.

Manabe, S.; Wetherald, R. T. 1986. Reduction in summer soil wetness induced by an increase in atmospheric carbon dioxide. Science. 232: 626-628.

Manning, S. J.; Groeneveld, D. P. 1989. Shrub rooting characteristics and water acquisition on xeric sites in the western Great Basin. In: McArthur, E. D.; Romney, E. M.; Smith, S. D.; Tueller, P. T., compilers. Proceedings—symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 238-244.

Mitchell, J. F. B. 1989. The "greenhouse" effect and climatic change. Reviews of Geophysics. 27: 115-139.

Reynolds, T. D.; Fraley, L. 1989. Root profiles of some native and exotic plant species in southeastern Idaho. Environmental and Experimental Botany. 29: 241-248.

Ritchie, G. A.; Hinckley, T. M. 1975. The pressure chamber as an instrument for ecological research. Advances in Ecological Research. 9: 165-254.

Rundel, P. W.; Ehleringer, J. R.; Nagy, K. A. 1988. Stable isotopes in ecological research. Berlin: Springer-Verlag. 525 p.

Schlesinger, M. E.; Mitchell, J. F. B. 1987. Climate model simulations of the equilibrium climatic response to increased carbon dioxide. Reviews of Geophysics. 25: 760-798.

Sokal, R. R.; Rohlf, F. J. 1981. Biometry. 2d ed. New York: Freeman. 859 p.

Sturges, D. L. 1977. Soil water withdrawal and root characteristics of big sagebrush. American Midland Naturalist. 98: 257-274.

White, J. W. C. 1988. Stable hydrogen isotope ratios in plants: a review of current theory and some potential applications. In: Rundel, P. W.; Ehleringer, J. R.; Nagy, K. A., eds. Stable isotopes in ecological research. Berlin: Springer-Verlag: 142-162.

White, J. W. C.; Cook, E. R.; Lawrence, J. R.; Broecker, W. S. 1985. The D/H ratios of sap in trees: implications for water sources and tree ring D/H ratios. Geochimica et Cosmochimica Acta. 49: 237-246.

RESPONSE OF RIPARIAN SHRUBS TO DECLINING WATER AVAILABILITY

Keith Boggs
T. Weaver

ABSTRACT

Community dominance, productivity, and grazing effects were recorded in a cottonwood sere along the Yellowstone River. The sere progressed from seedlings of Great Plains cottonwood (Populus deltoides) *and sandbar willow* (Salix exigua), *to cottonwood forests with a dense shrub understory, and then to grasslands. Total shrub canopy cover and biomass rose as sandbar willow matured, declined as they died, rose again as shrubs developed under the cottonwood canopy, and declined as grasslands dominated.*

INTRODUCTION

Our objectives were to document changes in plant composition, net primary productivity, and potassium mass, and to observe the effects of grazing on shrub composition in a cottonwood sere. Vegetation growing on new alluvial deposits nearer the stream may be contrasted with that on older deposits farther inland to recognize and measure successional processes (Jenny 1980; Leopold and others 1964; Stevens and Walker 1970). The sere described here progresses from seedlings of Great Plains cottonwood establishing on newly deposited alluvium, to a thicket of sandbar willow and cottonwood, to cottonwood forest, to a shrubland dominated by western snowberry (*Symphoricarpos occidentalis*) and woods rose (*Rosa woodsii*), and then to a self-perpetuating grassland dotted with silver sagebrush (*Artemisia cana*). The cottonwood-to-grassland sere is one of the dominant riparian seres in this region of the Northern Great Plains.

The study area was located on a 72-km stretch of floodplain along the lower Yellowstone River in Montana. It is the longest undammed river in the arid Western United States and has a floodplain whose water-erosion-deposition dynamics are intact. The region has a semiarid climate (Thornwaite 1941) supporting grass and shrub vegetation on the uplands.

METHODS

The study plan was to first identify the sere and seral stages during reconnaissance of the study area. Seven successional stages were identified on the floodplain and are presented in a chronosequence: sandbar, cottonwood

seedling, cottonwood sapling, cottonwood pole, mature cottonwood, shrub, and grassland. Sixty-six stands representing the sere were located along the length of the study area. One transect, 60 m in length, was placed in each stand. The following variables were recorded or sampled along the transect in each stand: plant species list, canopy coverage, cottonwood age, elevation of the land surface relative to the river surface, density of the dominant woody vegetation, harvest plots of herbaceous species, and soil cores to 15 dm deep.

Percent cover of understory plants was measured with 60 step points along the transect in each stand. Shrub cover was calculated by summing areas (Pi $\cdot$ r^2) of all shrubs present in density plots (described later) and dividing by total plot area. Tree canopy cover was estimated ocularly.

Stand age was estimated by counting the rings of typical cottonwood trees cut at the base (seedlings and saplings) or cored at breast height (pole and mature trees).

Elevation of the land surface relative to the river surface was used to determine rate of alluvial deposition. Stand elevation was determined with a measuring rod and hand level.

Tree and shrub densities per stand were recorded. These density measurements were later used to calculate total biomass of each stand. Aboveground biomass was estimated for five stands per stage by summing the mass of the tree, shrub, herb, and litter components. Individual tree and shrub mass was determined using allometric equations, and herb and litter mass was measured by harvesting a subsample of the stand. Dry mass of individual cottonwood trees in each stand was estimated from a tree dry mass/stem diameter regression using 10 cottonwood trees of various sizes (Boggs 1984). The mass of the tree layer was determined by estimating the dry mass of each tree from its diameter, summing across all trees in the density plots, and adjusting to a square-meter basis (Kira and Shidei 1967; Whittaker and Woodwell 1968). Sandbar willow, peach-leaved willow (*Salix amygdaloides*), western snowberry, woods rose, and silver sagebrush were similarly estimated using numbers and crown diameters of shrubs in the density plots. Aboveground mass for grasses, forbs, and litter was determined by harvesting, drying, and weighing the material present in five 0.5-m^2 plots spaced equally along the transect line in each stand.

Belowground biomass was estimated for the same five stands per stage used for aboveground biomass. The following categories were measured: root crowns, roots with diameters >1 cm, and soil organic matter. To estimate the mass of root crown and roots >1 cm we used a root mass/stem diameter regression constructed from six

cottonwood trees either excavated or found prewashed on sandbars (Boggs 1984). Total soil organic matter was estimated from three soil cores (0-15 dm in depth) from each transect. The cores were dried, ground (with roots), and analyzed for organic matter colorimetrically after dichromate oxidation (Sims and Haby 1970).

Net primary productivity was taken as the rate of change in standing crop implied by biomass and age estimates on the chronosequence plots. Because net primary production (kg/m²/yr) is change in mass per unit of time, it can be estimated as the slope of a line resulting when standing crop (kg/m²) is plotted against time.

The same five stands per stage used for biomass estimates were used for the potassium mass estimates. The plant contribution was determined by multiplying the estimated biomass component mass by potassium concentrations. For each species, five samples of leaves from wood of diameter classes 0-1, 1-10, and >10 cm were analyzed for potassium, and the results averaged. Potassium concentrations in roots <0.1 cm in diameter were assumed to equal 0-1-cm twig concentrations and >1 cm root concentrations were assumed to equal those of 1- to 10-cm branches. Potassium was determined by ashing samples and determining quantities of the nutrients released by spectrophotometric methods (Olson and Dean 1965).

Soils sampled for root mass and organic matter were used for potassium analyses and soil potassium mass estimates. The mass of soil potassium per stand was estimated by multiplying potassium concentrations (g/100 g) from the soil by soil bulk density by the volume of soil. Bulk density was estimated by dividing soil mass by sample volume; volumes were calculated by multiplying core area by core depth and adjusting to a square-meter basis. Potassium was extracted from soils with $1 M$ ammonium acetate and measured by atomic absorption (Pratt 1965).

The effects of grazing on the shrub component were determined by observations in stands of known grazing intensity, ranging from light to heavy grazing.

RESULTS AND DISCUSSION

Because cottonwood seedlings were recorded only on recent alluvial deposits, and all cottonwood stands were even-aged, cottonwood age was a direct measure of stand age. This was consistent with reports from other parts of the Great Plains (Johnson and others 1976; Moss 1938). With the death of the oldest cottonwood trees, the relatively precise cottonwood chronology ceased.

Trees and shrubs that appeared in over 60 percent of the stands of any stage are listed with cover estimates in table 1. In the cottonwood seedling stage, sandbar willow, peach-leaved willow, cottonwood, and herbaceous seedlings colonized new alluvial deposits of silt, sand, and gravel. Cottonwood, willow, and shrub cover averaged 27 ± 5 SE. Sandbar willow and cottonwood also dominated the cottonwood sapling stage. Due to the loss of sandbar willow between the cottonwood sapling and cottonwood pole stages, cottonwood dominated the cottonwood pole stage with an average canopy cover of 66 ± 4 SE. The undergrowth had a scattering of shrubs including woods rose and western snowberry with an average canopy cover of 5 ± 1 SE. Cottonwood canopy cover decreased to 40 ± 4 SE in the mature cottonwood stage. The shrub understory component increased dramatically to 19 ± 4 SE. The stand's appearance became one of widely spaced, dying cottonwoods.

With the disappearance of cottonwoods either of two communities assumed dominance: a shrub stage composed of woods rose and western snowberry or a green ash (*Fraxinus pennsylvanica*) forest. Stands supporting green ash were uncommon in the study area and consequently are not presented. Shrubs in the shrub stage had an average canopy cover of 23 ± 2 SE (table 1). Few dead shrubs were observed in the mature cottonwood stage, while ocular estimates of percent dead shrubs in the shrub stage ranged from 20 to 50 percent. The shrub stage was seral to a self-perpetuating grassland stage dominated by western wheatgrass (*Elymus smithii*) and prairie sandreed (*Calamovilfa longifolia*), and dotted with silver sagebrush. The herbaceous cover averaged 67 ± 3 SE and silver sagebrush averaged 1 ± 0 SE.

Table 1—Canopy coverage of trees and shrubs which occurred in >60 percent of the stands in six seral stages. The stages include: seed (cottonwood seedling), sapling (cottonwood sapling), pole (cottonwood pole), mature (cottonwood mature), shrub (shrub), and grass (grassland)

Plant species	Habit	Canopy coverage ($\bar{X}$±SE)					
		Seed	Sapling	Pole	Mature	Shrub	Grass
Populus deltoides	Tree	21±3	30	66±4	40±4	<1	—
Salix exigua	Shrub	5±2	30	—	—	—	—
Salix amygdaloides	Tree	1±1	5	<1	<1	—	—
Toxicodendron rydbergii	Shrub	—	—	<1	12±3	3±1	<1
Vitis riparia	Liana	—	—	<1	4±2	—	—
Ribes aureum	Shrub	—	—	<1	<1	<1	—
Parthenocissus inserta	Liana	—	—	<1	1±0	<1	<1
Ribes setosum	Shrub	—	—	—	—	<1	—
Rosa woodsii	Shrub	—	—	<1	12±3	14±2	<1
Fraxinus pennsylvanica	Tree	—	—	<1	<1	<1	—
Symphoricarpos occidentalis	Shrub	—	—	<1	6±2	8±1	<1
Artemisia ludoviciana	Shrub	—	<1	<1	<1	<1	2±1
Artemisia cana	Shrub	—	—	—	—	—	1±0

Estimates of water availability were made using the elevation of the ground surface above the river water surface, and changes in potassium mass. The rate of alluvial deposition during the 0- to 20-yr period was 0.11 m/yr, which rapidly raised the ground surface level above the river water surface to approximately 2.2 m (fig. 1). The rate of alluvial deposition was less thereafter, 0.01 m/yr, raising the ground surface level to 3.0 m at 110 yr. The rapid increase in ground surface level produces a corresponding decrease in flooding frequency.

Potassium is loosely bound by soils and organic matter and is easily delivered by river and groundwater, and leached by precipitation. Groundwater from the adjacent uplands and river water account for the majority of water and potassium inputs into the ecosystem. Ecosystem contents of organic and ammonium acetate extractable potassium rose, leveled off, and fell in time (fig. 2). Approximately 0.05 kg/m² was initially deposited on new alluvial bars, rose to 0.35 kg/m² in the mature cottonwood stage, and fell to 0.25 kg/m² in the grassland stage. This suggests that water availability is highest during the period of rapid alluvial deposition, and when the community is horizontally and vertically nearest the river. The river water imports are surely due to periodic flooding, a high water table, and pumping from the water table by the relatively deep-rooted cottonwood. During the conversion of the cottonwood forest to grassland, potassium loss from the total ecosystem, about 100 g/m² (fig. 2), may be influenced by the release of 40 g/m² stored in cottonwood biomass. Leaching of potassium by precipitation (30-35 cm/yr), which has been steady through succession, the loss of cottonwoods pumping potassium from the water table, and reduced flooding may account for most of the potassium loss.
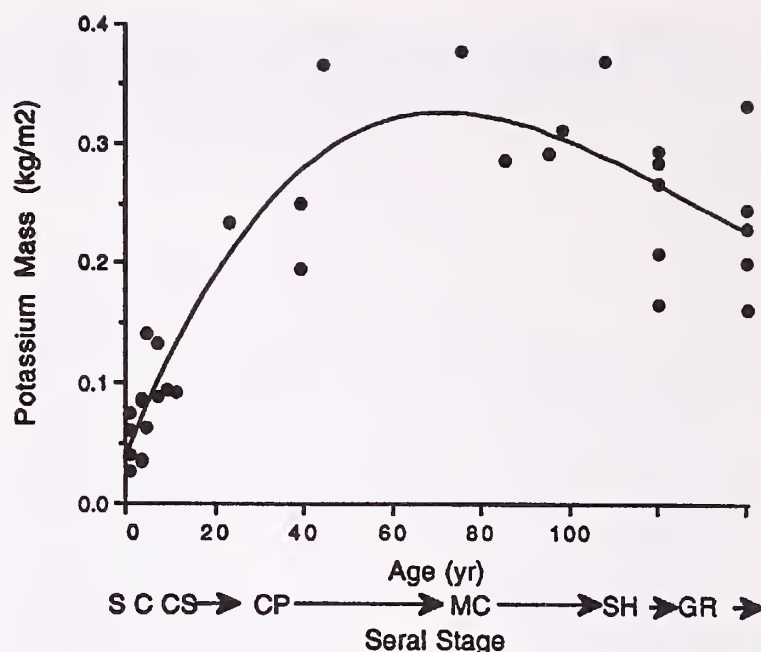
Figure 2—Ecosystem content of potassium (K). Totals include contents of soil and plant materials, both living and dead, and above and below ground. Letters represent the seral stages: sandbar (S), cottonwood seedling (C), cottonwood sapling (CS), cottonwood pole (CP), mature cottonwood (MC), shrub (SH), and grassland (GR).

Total biomass increased as the cottonwoods matured and decreased dramatically with the loss of cottonwoods. Changes in aboveground biomass by lifeform illustrate changes in community composition. Willow mass first dominated the sandbars; after 10 yr cottonwood mass exceeded that of willow (fig. 3). As cottonwood stands thinned after about 100 yr, understory shrubs, primarily woods rose and western snowberry, reached their greatest live biomass. As the shrub stage is replaced by the grassland stage, shrub biomass decreased with the loss of snowberry and woods rose. The massive dominance of cottonwood in the 20-100 yr period was understated in figure 3 due to the division of its biomass by 20. Whereas water availability is highest in the early seral stages, community biomass is limited by the degree of community development and reaches its peak as the cottonwood forest matures. With the eventual death of the cottonwoods, aboveground biomass is limited by the lack of regeneration of any tree species in the shrub and grassland stages. Cottonwood trees evidently tap the water table, but as they die they are eventually replaced by species, such as silver sagebrush and western wheatgrass, that have far lower transpiration requirements.

Aboveground net primary production was positive (0.4 kg/m²/yr) when the ecosystem was young, approached neutral in the 80- to 110-yr period, was negative as the cottonwood forests died, and approached neutral in the shrub and grassland stages. Aboveground net primary productivity in the sandbar-through-mature cottonwood stages is below that of other temperate forests. The steepest upward slope (0.4 kg/m²/yr) is below the 0.6 to 2.5 kg/m²/yr range reported for temperate deciduous
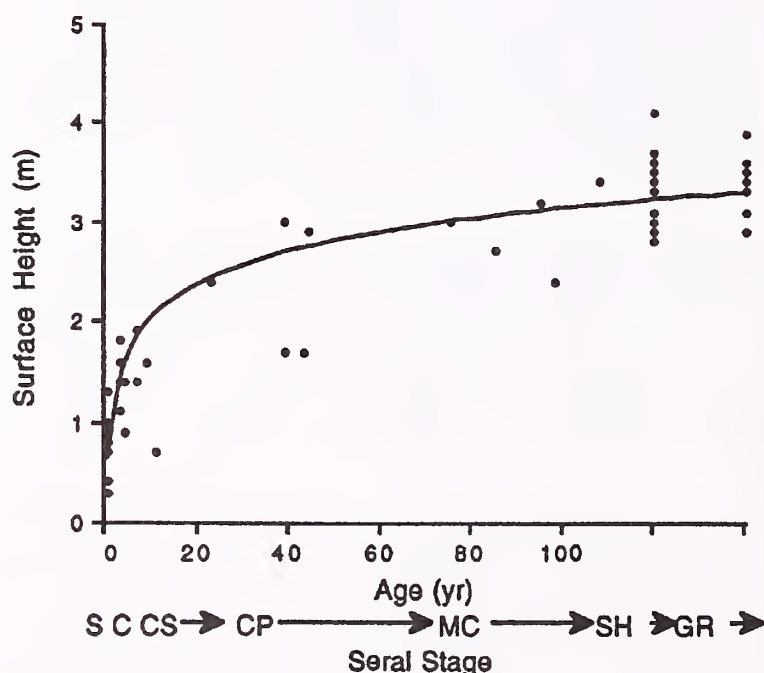
Figure 1—Ground surface elevation above the river water level. Letters represent the seral stages: sandbar (S), cottonwood seedling (C), cottonwood sapling (CS), cottonwood pole (CP), mature cottonwood (MC), shrub (SH), and grassland (GR).

Figure 3—Aboveground mass of cottonwood (*Populus deltoides*), willow (*Salix* spp.), and shrubs. Note the division of cottonwood by 20. Letters represent the seral stages: sandbar (S), cottonwood seedling (C), cottonwood sapling (CS), cottonwood pole (CP), mature cottonwood (MC), shrub (SH), and grassland (GR).
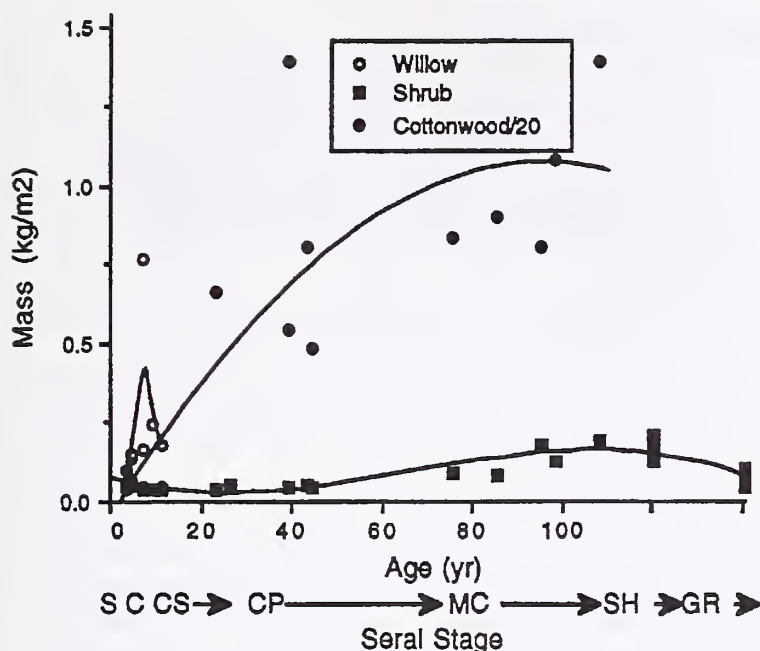
forests (Art and Marks 1971; Whittaker 1975). This low production rate can be attributed to a number of causes including: physical removal of organic matter by flood waters, saturated cold anaerobic soil conditions during flooding, and the loss of cottonwoods without regeneration. Approximately 50 percent of the aboveground organic matter is lost with conversion of the mature cottonwood stage to shrub and grassland stages.

On sites that are relatively ungrazed, the understory of the mature cottonwood forest will contain a diverse, dense shrub layer dominated by redosier dogwood (*Cornus stolonifera*), western serviceberry (*Amelanchier alnifolia*), common chokecherry (*Prunus virginiana*), western snowberry and woods rose, various species of willows (*Salix* spp.), and currants and gooseberries (*Ribes* spp.). With moderate grazing, there will be an increase in western snowberry and woods rose, with a corresponding decrease in both the abundance and canopy cover of redosier dogwood, western serviceberry, common chokecherry, and various species of currants and gooseberries. If the disturbance continues, the more palatable shrubs will be eliminated leaving woods rose and western snowberry, which can form a nearly impenetrable understory. However, if the disturbance is severe enough, shrubs can be eliminated and the understory will be converted to an herbaceous one dominated by species such as Kentucky bluegrass (*Poa pratensis*), common timothy (*Phleum pratensis*), and smooth brome (*Bromus inermis*). During the process of converting from a diverse, dense shrub understory to an herbaceous understory, the stand will open up, resulting in a drier site. Once the stand has converted from a shrub-dominated understory to one that is

dominated by a variety of introduced herbaceous species, the ability to return the site to its former state (shrub dominated) is very difficult. It may be possible, but it will require a drastic change in management. Therefore, if the manager wants to maintain the stand in a shrub-dominated understory state, change the management on the site before the site is degraded.

ACKNOWLEDGMENTS

REFERENCES

Art, H.; Marks, P. 1971. A summary table of biomass and net annual primary production in forest ecosystems of the world. In: Young, H., ed. Forest biomass studies, procceedings 15. IUFRO Conference. Orono, ME: Forest Agricultural Experiment Station, University of Maine: 2-32.

Boggs, K. 1984. Succession in riparian communities of the lower Yellowstone River, Montana. Bozeman, MT: Montana State University. 107 p. Thesis.

Jenny, H. 1980. The soil resource. New York: McGraw-Hill. 281 p.

Johnson, W.; Burgess, R.; Keammerer, W. 1976. Forest overstory vegetation and environment on the Missouri River floodplain in North Dakota. Ecological Monographs. 46: 59-84.

Kira, T.; Shidei, T. 1967. Primary production and turnover of organic matter in different forest ecosystems of the western Pacific. Japan Journal of Ecology. 17: 70-87.

Leopold, L.; Wolman, M.; Miller, J. 1964. Fluvial processes in geomorphology. San Francisco: Freeman and Company. 2 p.

Moss, E. 1938. Longevity of seed and establishment of seedlings in species of *Populus*. Botanical Gazette. 99: 529-542.

Olsen, S.; Dean, L. 1965. Phosphorus. In: Black, C., ed. Methods of soil analysis. Madison, WI: American Society of Agronomy: 1035-1045.

Pratt, P. 1965. Potassium. In: Black, C., ed. Methods of soil analysis. Madison, WI: American Society of Agronomy: 1022-1030.

Sims, J.; Haby, V. 1970. Simplified colorimetric determination of soil organic matter. Soil Science. 112: 137-141.

Stevens, P.; Walker, T. 1970. The chronosequence concept and soil formation. Quarterly Review of Biology. 45: 333-350.

Thornwaite, C. 1941. Climate and man. Washington, DC: U.S. Department of Agriculture: 633-654.

Whittaker, R. 1975. Communities and ecosystems. New York: Macmillan. 387 p.

Whittaker, R.; Woodwell, G. 1968. Dimension and production relations of trees and shrubs in the Brookhaven Forest, New York. Ecology. 56: 1-25.

245

FIRE IN A RIPARIAN SHRUB COMMUNITY: POSTBURN WATER RELATIONS IN THE *TAMARIX-SALIX* ASSOCIATION ALONG THE LOWER COLORADO RIVER

David E. Busch
Stanley D. Smith

ABSTRACT

Higher water potentials in recovering burned salt-cedar (Tamarix ramosissima) *relative to unburned plants and the opposite situation in willow* (Salix gooddingii) *provide evidence that postfire water stress is reduced in the former but not the latter. Similarly, diurnal patterns of stomatal conductance in these taxa are consistent with the existence of more vigor in burned salt-cedar than willow. Plots of water potential and transpiration demonstrate that hydraulic efficiencies may contribute to differences in fire recovery.*

INTRODUCTION

Alteration of hydrologic regimes by humans has indirectly impacted communities dominated by woody phreatophytic vegetation along watercourses of the Southwest. The invasion of low-elevation riparian communities throughout western North America by salt-cedar (*Tamarix ramosissima*) may have been aided by the cessation of disturbance from flooding. Moreover, salt-cedar may be both the cause and the beneficiary of a new suite of disturbances, prominent among which is fire.

Alluvial soils are frequently covered by several centimeters of salt-cedar leaf litter to the exclusion of other plants (Haase 1972). Such fuel buildup causes fire with a repetitive frequency of <20 yr in North American desert riparian settings; this has led to the demise of communities dominated by cottonwood (*Populus fremontii*) and willow (*Salix gooddingii*) along the lower Colorado River (Ohmart and others 1977). It is uncertain whether or not fire was important in structuring riparian vegetation communities dominated by cottonwood, willow, or mesquite (*Prosopis* sp.) prior to salt-cedar invasion, but we think that its role was minor. There are few indications that salt-cedar is considered fire-adapted from throughout its native Eurasian range. Provided that fire was historically unimportant, the invasion of salt-cedar with an accompanying propensity for episodic burning has produced a unique disturbance regime in low-elevation southwestern flood plain ecosystems.

The adaptation of salt-cedar to resprout rapidly following fire has been implicated in its rapid colonization of water courses throughout the Southwest (Crins 1989). Roots of salt-cedar are capable of forming adventitious shoots, and stem tissue will sprout vigorously given the proper conditions (Gary and Horton 1965; Wilkinson 1966). Rootstocks of the Salicaceae also are known to sprout vigorously (Fowells 1965). There is evidence for a dependence on groundwater in both willow and salt-cedar based on soil moisture depletion (McQueen and Miller 1972) and water uptake (D. E. Busch, in preparation). Salt-cedar root distribution is well developed in the water table and overlying capillary zone (Gary 1963). Willow (*S. nigra*) groundwater dependence is suggested by inundation tolerance and intolerance of moisture stress (Dionigi and others 1985).

Areas where relict native willow codominates with salt-cedar provide opportunities to study putative competitive factors that may favor the exotic. Similarities in phreatophytic life histories and fire recovery mechanisms led us to hypothesize that postburn water relations may contribute to differential recovery between these taxa.

MATERIALS AND METHODS

Water relations data were collected during the 1989 growing season at two sites in the Arizona flood plain of the Colorado River near Needles, CA (34°50' N., 114°35' W., 150 m elevation). The sites were separated by <2 km and were both 150-200 m from the river. Depth to ground water, as measured with onsite piezometers, averaged (± S.D.) 3.53 ± 0.47 m. The study area was characterized by a tall scrub association dominated by salt-cedar and willow, which form dense thickets with interlocking canopies. Arrowweed (*Tessaria sericea*) was also abundant on these sites. Screwbean (*Prosopis pubescens*) was scattered throughout unburned portions of the flood plain.

Data were collected from single willow and salt-cedar coppices at three sublocations within this vegetation association that showed no sign of recent surface disturbance (controls). The burned site, which had been disturbed by an intense fire in 1986, had no screwbean but was experiencing regrowth of the other three taxa. Resprouting willow and salt-cedar coppices were again selected at three sublocations within the burned area. Mean growing season gravimetric soil moisture in the upper 90 cm of the soil profile was lower for burned sublocations (1.19 ± 0.12 percent) than for control sublocations (3.77 ± 1.24 percent). It is

uncertain if this condition predated the fire or if the effects of burning or subsequent soil exposure to enhanced evaporative conditions contributed to this difference.

Total water potential (Ψ) was measured twice daily on each plant, before dawn (Ψ_{max}) and at midday (Ψ_{min}). Measurements were made using the pressure chamber technique (Turner 1988) with a PMS Model 1000 pressure chamber apparatus on 10-30 cm terminal branches taken from the midcanopy level. Upon cutting, branches were immediately placed in polyethylene bags and housed on ice and in the dark until pressurization, which was quickly conducted at the site. Stomatal water vapor conductance (g) and transpiration (E) were measured using a steady-state porometer (Licor LI-1600). Salt-cedar cladophyll morphology necessitated the use of a cylindrical chamber, so this type of cuvette was used for willow as well. Diurnal curves for these parameters were developed from pormeter readings made at 2-hour intervals. For between-site comparative purposes g_{max} was calculated by averaging g values from 9 a.m. to 1 p.m. Although willow is amphistomatous, area-specific g and E data reported here were based on a single projected leaf surface.

Between-site statistical comparisons were made by testing for differences using the Mann-Whitney test for two independent samples (Conover 1990). Test statistics (U) and probabilities of a Type I error are presented where results of this nonparametric test were significant ($P < 0.05$). Simple linear regression models were derived to examine the tendency of Ψ to vary with daily increases in E.

RESULTS AND DISCUSSION

For both salt-cedar and willow there was a modest tendency for Ψ_{max} to be lower (more negative) during the summer months with recovery demonstrated in autumn (fig. 1). Predawn Ψ showed no significant differences between burned and unburned study sites for either species in either season. The lack of strong site or seasonal differences in Ψ_{max} is consistent with the phreatophytic habit. Apparently the roots of both taxa maintain contact with groundwater or the capillary fringe, and this connection is retained after burning. Predawn Ψ levels for willow over the study's course were lower than those reported for other temperate hardwood species (Abrams 1988), but are not considered stressful for a mesophyte. Salt-cedar Ψ_{max} levels are considerably lower than those reported elsewhere (Anderson 1982), but probably do not indicate water stress for a halophyte that may successfully utilize low osmotic potentials in the water uptake process.

Figure 1 indicates that, for salt-cedar, Ψ_{min} levels on the burn site were not significantly different from those in control coppices. Midday Ψ was significantly ($U = -3.078$, $P < 0.005$) more negative for resprouting burned willow than in controls. On an absolute basis, these are substantially lower Ψ's than have previously been reported for salt-cedar or willow (Abrams 1988; Anderson 1982). However, it is difficult to determine if these levels should be considered stressful in salt-cedar due to its presumed osmotic adjustment adaptations. Although we are pursuing this question with research into phreatophyte tissue water relations, we feel that it is unlikely that salt-cedar experiences water stress on burned sites in view of the lack of significant difference from control plants and the success of its
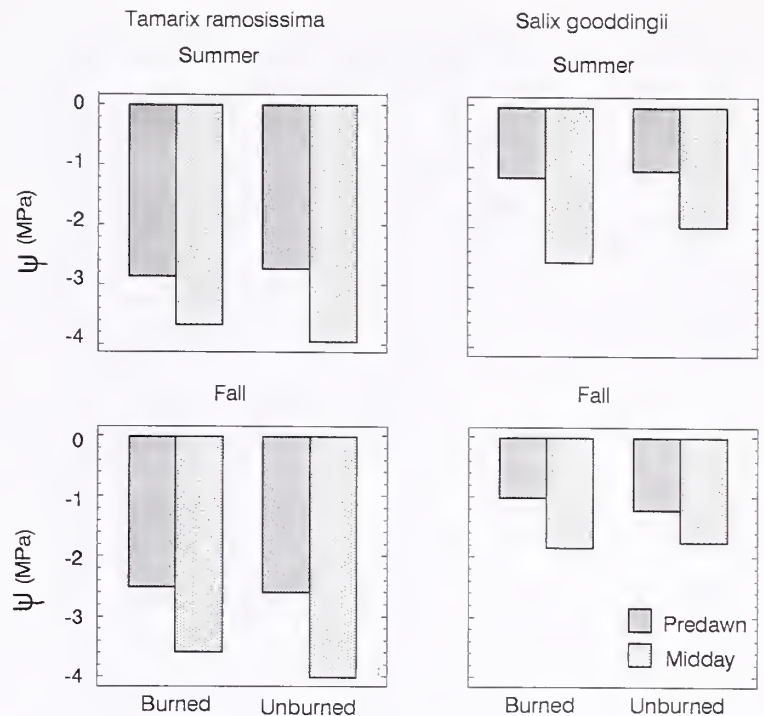
Figure 1—Mean ($n \geq 12$ in all cases) predawn (Ψ_{max}) and midday (Ψ_{min}) water potential in burned and unburned salt-cedar (left) and willow (right) from the lower Colorado River during summer (upper) and autumn (lower) 1989.

recent invasion in the lower Colorado River flood plain. Wilting has been reported for flooded willow at <-1.8 MPa (Dionigi and others 1985). The Ψ_{min} values reached by willow are well below levels thought to reduce photosynthetic capacity and growth in mesophytes (Hsiao 1973). Thus, resprouting willow on burned areas do appear to demonstrate at least transitory water stress.

The short-term water stress shown in burned willow does not appear to induce stomatal closure (fig. 2). While g_{max} on burned and control sites did not differ significantly during the summer, autumn values were significantly higher in plants that had burned ($U = -4.412$, $P < 0.001$). Stomatal conductance patterns for salt-cedar are dissimilar from reports of constant leaf resistance (Anderson 1982) in that a marked late-morning decline was noted in summer (fig. 2). This indicates a degree of stomatal control may be exhibited under mild water stress in this species. Throughout the study's course, salt-cedar g_{max} on burned sites significantly exceeded that on control sites ($U = -4.835$, $P < 0.001$). Beyond confirming our previously stated finding that recovering burned salt-cedar is not water stressed, diurnal stomatal conductance data suggest that rhizosphere water availability is not limiting, and may actually facilitate its reestablishment. Interpretation of the willow results is more problematic, but it is clear that enhanced leaf diffusive conductance did not occur during the summer in burned plants in the manner that it did in salt-cedar.

The relationship between water potential and transpiration offers greater insight into soil moisture limitations than predawn water potential alone (Bates and Hall 1982). To further compare differences in plant water status, the effects of E on Ψ were modeled using linear regression (fig. 3). Although a linear model for burned salt-cedar was acceptable, the significance of the regression for controls

53
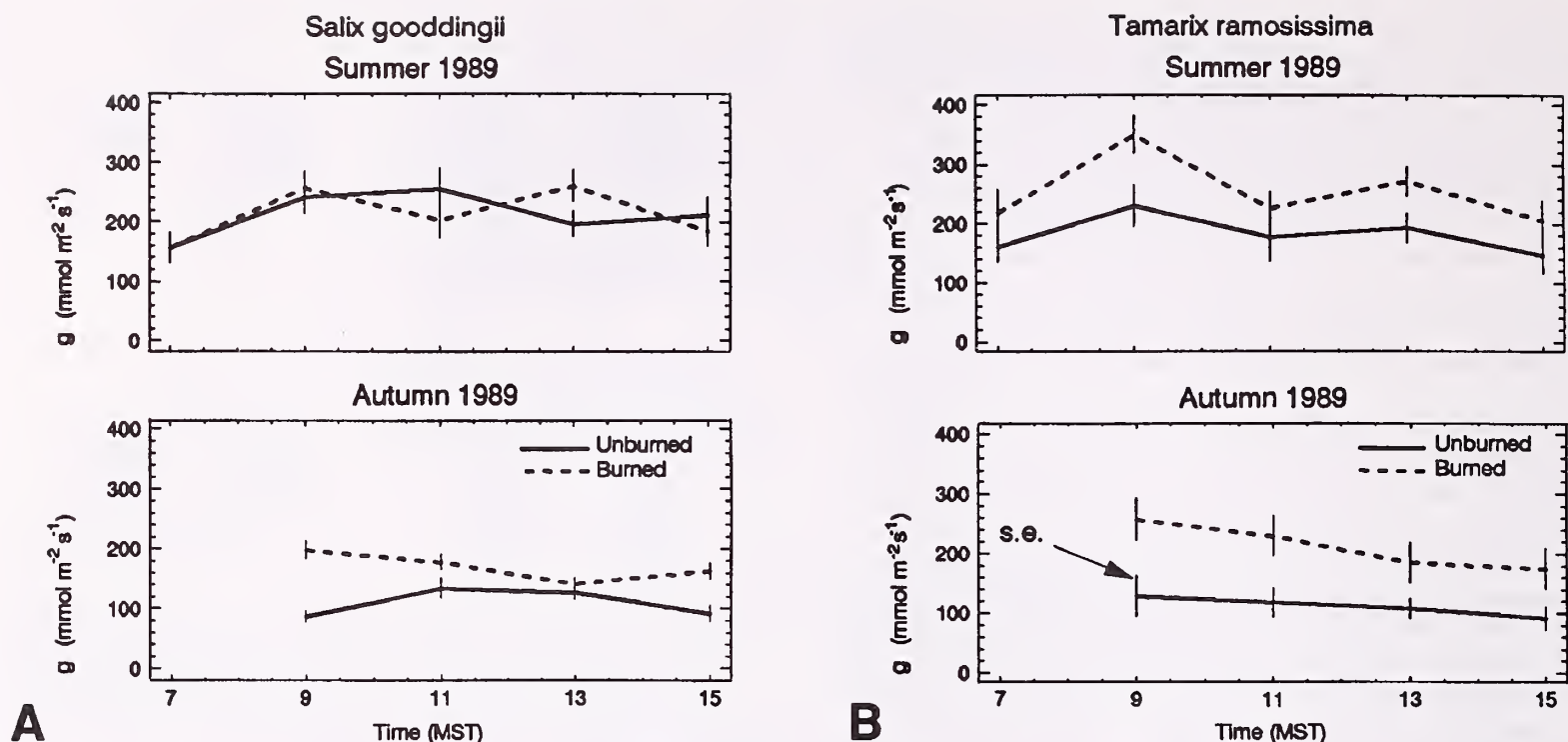
Figure 2—Stomatal conductance (g) response curves for willow (A) and salt-cedar (B) from burned and unburned sites in the lower Colorado River flood plain during summer and fall 1989. Each point represents the mean ($n \geq 18$) ± associated standard error.

was low ($r^2 = 0.27, P > 0.05$). Since inferences could not be made for the latter setting and also since interspecific comparisons of porometer-derived E would be meaningless, we elected not to pursue this analysis for salt-cedar. In willow the slope of depression for burned trees was less than that for controls (fig. 3). This is evidence for decreased efficiency of water uptake and transport in the post-fire condition. Lower hydraulic efficiency in burned willow signifies reduced productivity, which is a likely result of diminished effective root:shoot ratio (Bates and Hall 1982).

It has been hypothesized that plant species possessing resprouting mechanisms that are activated by burning might have also developed via natural selection character-istics that enhance the flammability of the communities where they grow (Mutch 1970). We have provided evidence that would support a hypothesis of competitive superiority in water acquisition of burned and resprouting coppices of salt-cedar relative to those of willow. Accumulation of flam-mable leaf litter beneath salt-cedar appears to contribute to episodic fires, which aid the invasion of this exotic. Is this situation an anomaly in North American communities dominated by this naturalized phreatophyte or does it repre-sent "true" adaptation to fire? This might best be answered by demographic analyses of *Tamarix* associations in Eurasia. Although it resprouts vigorously following fires, our data suggest that willow is hydraulically less efficient than co-occurring salt-cedar. Interactions between these taxa, paired with the impact from fire, would tend to favor the introduced species. Intercorrelated with these factors are other forms of disturbance, which were not discussed here. The complex suite of recently altered environmental factors that has confronted native riparian trees is thus likely to have led to impacts ranging from direct mortality to reduced propagule dissemination and establishment.
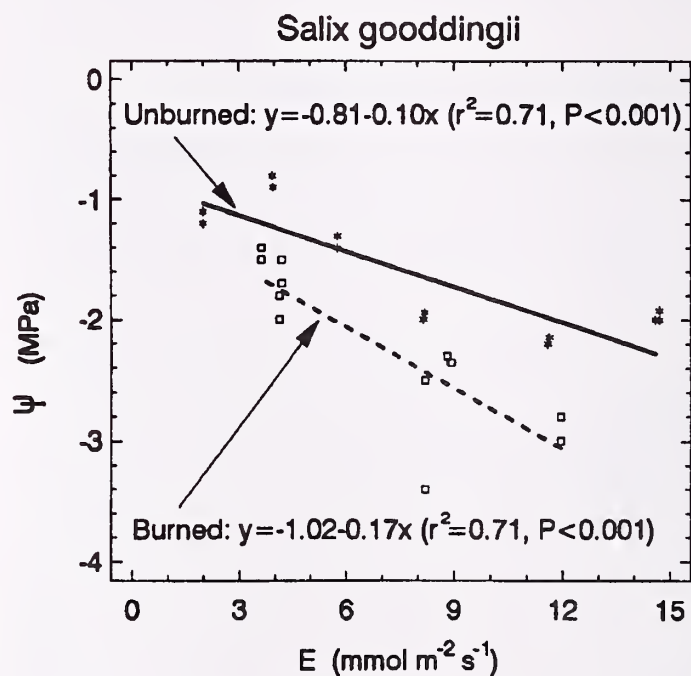
Figure 3—Regressions of water potential (Ψ) on transpiration (E) for burned and unburned willow from the lower Colorado River riparian zone during the 1989 growing season.

ACKNOWLEDGMENTS

REFERENCES

Abrams, M. D. 1988. Comparative water relations of three successional hardwood species in central Wisconsin. Tree Physiology. 4: 263-273.

Anderson, J. E. 1982. Factors controlling transpiration and photosynthesis in *Tamarix ramosissima* Lour. Ecology. 63: 48-56.

Bates, L. M.; Hall, A. E. 1982. Relationships between leaf water status and transpiration of cowpea with progressive soil drying. Oecologia. 53: 285-289.

Conover, W. J. 1980. Practical nonparamatic statistics. New York: John Wiley and Sons. 493 p.

Crins, W. J. 1989. The Tamaricaceae in the southeastern United States. Journal of the Arnold Arboretum. 70: 403-425.

Dionigi, C. P.; Mendelssohn, I. A.; Sullivan, V. I. 1985. Effects of soil waterlogging on the energy status and distribution of *Salix nigra* and *S. exigua* (Salicaceae) in the Atchafalaya River Basin of Louisiana. American Journal of Botany. 72: 109-119.

Fowells, H. A. 1965. Silvics of forest trees of the United States. Agric. Handb. 271. Washington, DC: U.S. Department of Agriculture, Forest Service. 762 p.

Gary, H. L. 1963. Root distribution of five-stamen tamarisk, seepwillow, and arrowweed. Forest Science. 9: 311-314.

Gary, H. L.; Horton, J. S. 1965. Some sprouting characteristics of five-stamen tamarisk. Res. Note RM-39. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 7 p.

Haase, E. F. 1972. Survey of flood plain vegetation along the lower Gila River in southwestern Arizona. Journal of the Arizona Academy of Science. 7: 75-81.

Hsiao, T. C. 1973. Plant responses to water stress. Annual Review of Plant Physiology. 24: 519-570.

McQueen, I. S.; Miller, R. F. 1972. Soil-moisture and energy relationships associated with riparian vegetation near San Carlos, Arizona. Prof. Pap. 655-E. Washington, DC: U.S. Geological Survey. 51 p.

Mutch, R. W. 1970. Wildland fires and ecosystems: an hypothesis. Ecology. 51: 1046-1051.

Ohmart, R. D.; Deason, W. O.; Burke, C. 1977. A riparian case history: the Colorado River. In: Johnson, R. R.; Jones, D. A., tech. coords. Importance, preservation and management of riparian habitat: a symposium. Gen. Tech. Rep. RM-43. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 35-47.

Turner, N. C. 1988. Measurement of plant water status by the pressure chamber technique. Irrigation Science. 9: 289-308.

Wilkinson, R. E. 1966. Adventitious shoots on salt-cedar roots. Botanical Gazette. 127: 103-104.

CLONE STRUCTURE OF SALMON-BERRY AND VINE MAPLE IN THE OREGON COAST RANGE

John Zasada
John Tappeiner
Mary O'Dea

ABSTRACT

*Salmonberry (*Rubus spectabilis*) and vine maple (*Acer circinatum*) form clones of varying sizes and densities on forest sites in the Oregon Coast Range. Clones of these species can be similar in size and dimensions. The method of clone formation is very different, however. Salmonberry clone development is an active process requiring the growth of a rhizome into an area and subsequent ramet production from the rhizome bud bank. Vine maple clone development in contrast is a relatively passive process. Stems layer when they are pinned to a suitable substrate by a fallen tree or branch. The number of points where rooting occurs is determined by the number of suitable contacts with the ground. This paper describes selected aspects of clone development and morphology in these species.*

INTRODUCTION

The forests of the Oregon Coast Range are among the most productive in North America. Conifer species—most notably Douglas-fir (*Pseudotsuga menziesii*)—are the dominant species in forest succession. They are the basis for the forest industry in the region, and forest management practices are designed to reestablish them quickly following harvesting. When people think of the Coast Range they often visualize relatively intensively managed, even-aged, Douglas-fir plantations.

However, lurking beneath and intermixed with the conifers is a group of plants that is euphemistically referred to by foresters as "brush" in a forgiving moment and "blankety-blank brush" at other times. Obscured by this generic euphemism is a group of important and interesting plants—broadleaved trees, shrubs, and herbs. There is no doubt that these species can cause major reforestation problems. However, they also play an important ecological role on these sites. The best known of these species is red alder because of its ability to fix nitrogen. Other species also play roles that are important to the functioning of the forest ecosystem—for example through addition to soil organic matter pools, as food and cover for wildlife, and through maintenance of soil stability and retention of

nutrients following disturbance. As land managers become more interested and concerned about biodiversity, forest structure, long-term site productivity, and wildlife and other issues, the value and importance of these species will increase.

To manage the Coast Range forests of Oregon for multiple-resource values, land managers must understand the biology of the species, their resource requirements, and their response to natural and human disturbance over a range of site conditions. During the last decade, and particularly the last 5 years, we have been studying selected aspects of the reproductive biology and population biology of some of the more common broadleaved trees and shrubs in the central Oregon Coast Range. We have concentrated on species that are most important as competitors for site resources with conifers following harvesting—for example, bigleaf maple (*Acer macrophyllum*), salmonberry (*Rubus spectabilis*), vine maple (*Acer circinatum*), salal (*Gaultheria shallon*), and red alder (*Alnus rubra*). These species represent a number of different growth forms and strategies for reproduction and colonization of sites (Burns and Honkala 1990; Haeussler and others 1990).

The two species described here are salmonberry and vine maple. They occur on upland and riparian sites in the Oregon Coast Range. Both have the capacity to form dense multiclone stands that may persist for long periods of time because of the difficulty that conifers and other species have in invading dense, pure stands of these species (Barber 1976; Maxwell 1990; Russel 1973; Tappeiner and others 1991). In this paper, we will discuss some general aspects of clone and stand structure and some implications that this structure has to their occupancy of riparian zone sites and management of these species. The discussion of salmonberry is partly based on Tappeiner and others (1991), and the information on vine maple is from research that is in progress.

SALMONBERRY CLONE AND STAND STRUCTURE

Salmonberry is a rhizomatous species, which spreads by active growth of the rhizome system (fig. 1). Individual clones (at least those ramets that are still physically connected) cover areas of up to 35 m². Stands are comprised of many groups of attached ramets. Based on circumstantial evidence such as rhizome diameter and the lack of large amounts of obvious decay of the rhizomes, we believe that clones break up slowly and that some individuals
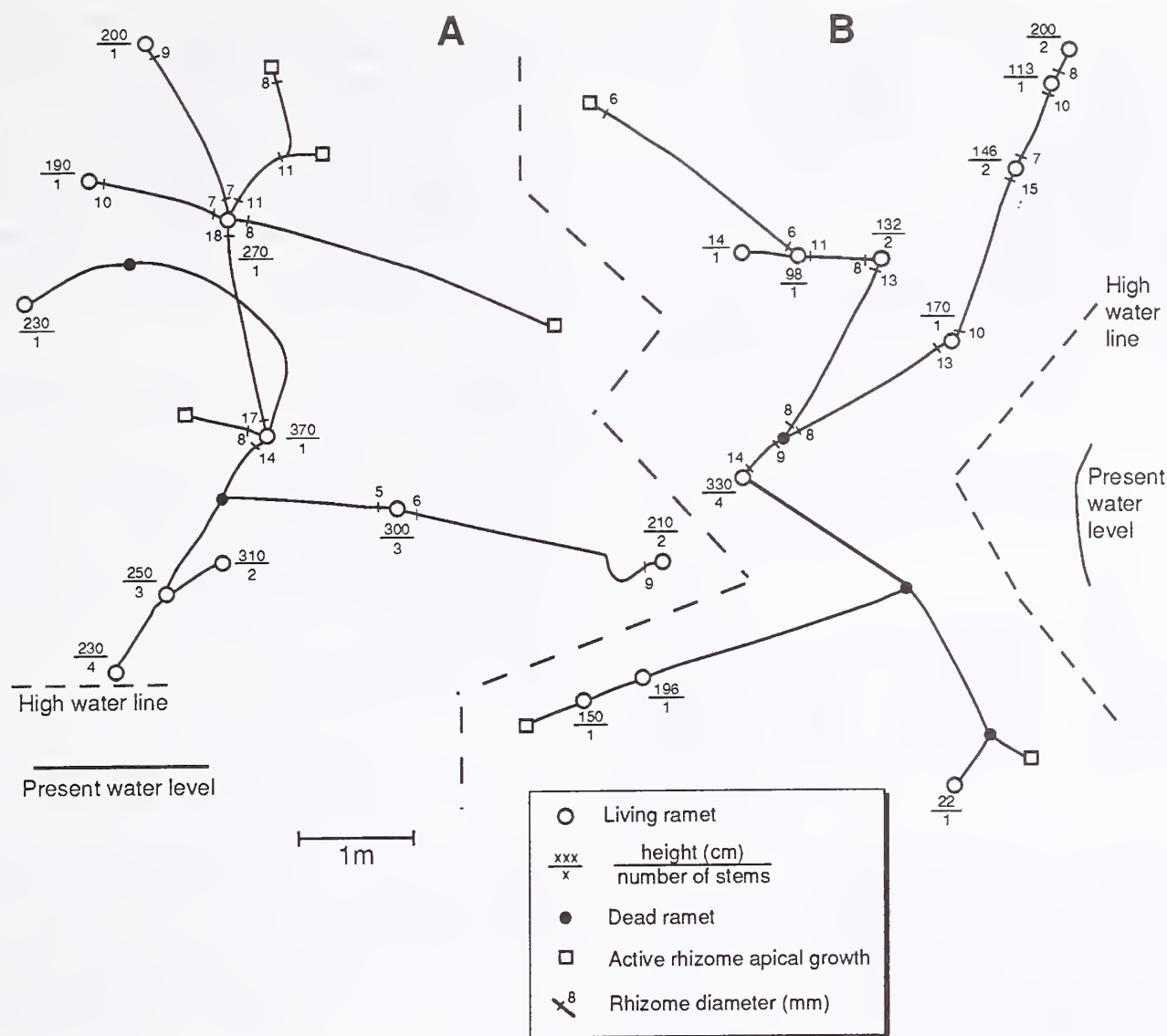
Figure 1—Representative salmonberry clones excavated from riparian zone sites in the central Oregon Coast Range. See Tappeiner and others (1991) for clone maps from upland sites.

retain a physical connection for many years. Observations made during the excavation of about 100 clones and many sample plots indicated that 4-5 clones (groups of ramets that are still physically connected by a rhizome) may contribute to the salmonberry population within a 4-m² area in a well-stocked salmonberry stand. The density of genets within a given stand is unknown. Genets in some cases are undoubtedly represented by more than one clone (as defined above).

The salmonberry rhizome consists of well-defined nodes and internodes, and density varies from 0.5 to 2 nodes per centimeter. The nodes are easiest to identify on new rhizome growth (see fig. 1 for an example of the frequency and distribution on new rhizomes within a clone) and tend to lose their distinguishing external characteristics when they are 60 to 75 nodes removed from the actively growing rhizome apical meristem. There is usually a preformed root primordia, or so it appears, associated with each node. Thus, each node has the potential for forming an independent plant under ideal conditions. Using data from Tappeiner and others (1991) and unpublished data, we estimated the potential rhizome bud bank in

well-stocked salmonberry stands located in 10- to 15-year-old clearcuts to be as high as 1 to 4 million buds per hectare.

The length of rhizome systems on a per-clone or per-unit-area basis appears to be closely related to overstory conditions. Annual rhizome extension is also related to overstory conditions. Following clearcutting, annual rhizome extension was from 1 to 3 m/m². Under stand conditions, both conifer- and alder-dominated overstories, rhizome extension was generally between 0.25 and 0.5 m/m² (Tappeiner and others 1991).

The diameter distribution of ramets in undisturbed stands is typical of that observed for uneven-aged populations of trees and shrubs (fig. 2A). In salmonberry, we have not been able to accurately age stems because annual rings are not well defined, and thus have no estimate of age distrbution for our stands (Barber 1976). However, we have been following stem populations for about 5 years on the same plots and know that stems can remain alive for longer than this length of time. The stem population in a stand consists of two components, the longer lived, larger stems and a variable number of stems that are
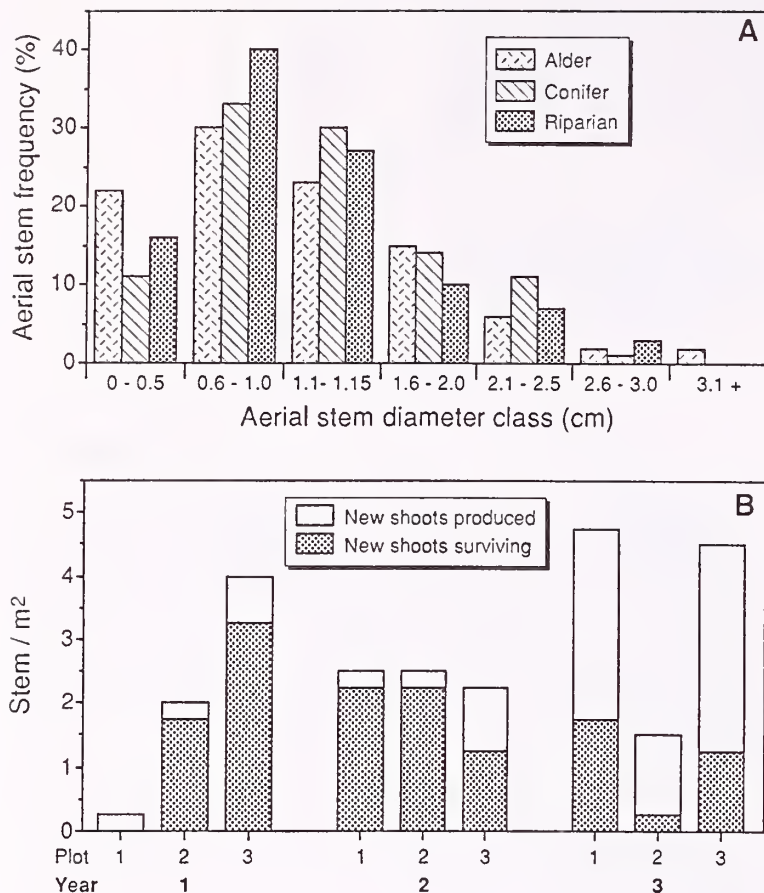
Figure 2—(A) Average salmonberry stem population frequency by stem diameter and stand type (adapted from Tappeiner and others 1991). (B) Variation in production of annual shoots on a riparian site in the Oregon Coast Range. Figure shows the number of current-year shoots present in early summer and late autumn.

rooting of a stem depends on whether or not it comes in contact with the substrate long enough for roots to develop. Snow can also be an important factor in flattening multistemmed clumps that subsequently layer (Russel 1973). Layering is greatly enhanced when woody material (trees or branches) falls on a part of the stem, pinning it to the substrate (fig. 3). Of the shrubs in the Oregon Coast Range that are known to layer, vine maple appears to be able to utilize the process to the greatest advantage in terms of increasing the area covered by an individual clone.

The physical structure of clones can vary greatly (fig. 4). The extremes range from upright stems in which no layering has occurred to clones in which all stems have been flattened and pinned to the surface at one or more points. In the latter case (fig. 4B), stem density can be 2-3/m² and clones can cover an area of 150-250 m². A typical clone will have an erect central group of stems (we have observed over 100 stems in this central group) and 3-5 layered stems. Distance of rooting from the clone center ranges from a meter or less up to 15 m, with 2-7 m being common. The number of times that a stem can root is

produced annually (fig. 2B). These annual cohorts exhibit large variation in survival within stands and among years.

Salmonberry rhizome or stand structure does not appear to differ significantly between upland and riparian sites (fig. 2A). We have observed some restricted rhizome development in riparian areas, but this appeared to be the result of unsuitable substrates and not due to any inherent differences between upland and riparian populations.

VINE MAPLE CLONE AND STAND STRUCTURE

Vine maple clone formation is based on the ability of an individual stem, present singly or in multistemmed groups, to root when it is in contact with a suitable substrate for a sufficient time period (layering) (Anderson 1969; Russel 1973). The multistemmed group that serves as the source of stems forms as the result of basal sprouting following disturbances such as fire or logging, or as a normal part of development from seed. Suitable rooting substrates include mineral soil, forest floor organic matter, rotten logs, and even rotten branches on standing trees. This form of clone expansion is passive in that

Figure 3—Vine maple clone showing original stem that was flattened by a fallen tree and the vertical stems produced as a result of disturbance. Root locations on the down stem are also shown. The dashed lines (– –) indicate the location of ramets that developed following pinning of the parent stem. These ramets are upright, but the length of the lines and stem heights indicate the horizontal coverage possible if all ramets were pinned—for example, the distance from a to b is about 19 m.
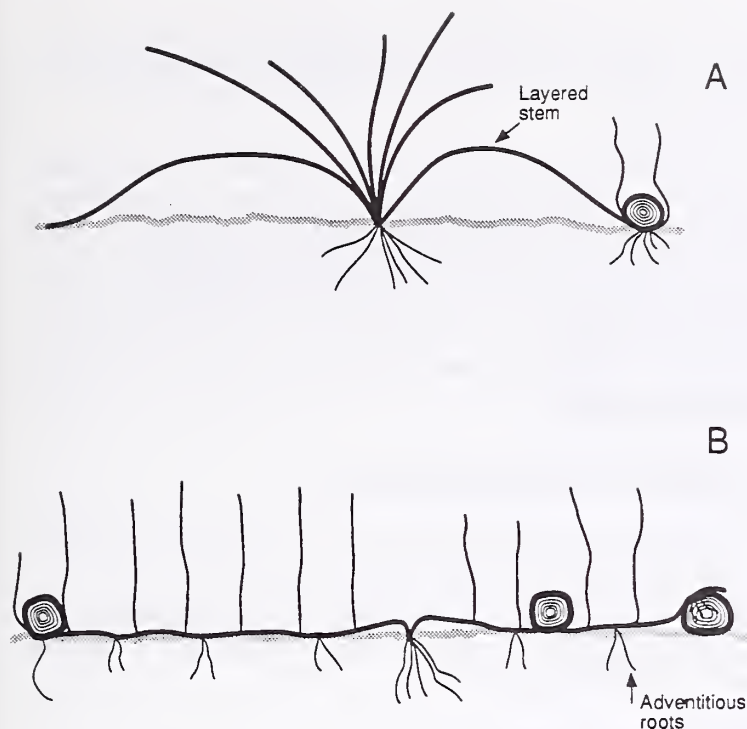
Figure 4—Idealized examples of several clone forms of vine maple. Typically, clones will have several upright stems and one or more layered stems (A). The densest clones are formed when all or a majority of the stems are pinned or flattened by fallen trees or other debris (B). In this case, each pinned stem often produces a number of stems and roots at several points. Darker and thicker horizontal and vertical lines represent original stems, and the thinner vertical lines, stems formed as a result of layering.

dependent on the number of points that come in contact with a suitable substrate. The number of points where the stem is in contact with the ground depends on the amount of debris falling on the stem, and the microtopography of the ground surface.

The range in age and size distribution of stems in a clone can be great. The oldest vine maple stem that we are aware of is 120-130 years old (for example, Russel 1973).

OCCURRENCE AND BEHAVIOR IN RIPARIAN AREAS

From the descriptions given earlier it is obvious that salmonberry and vine maple differ significantly in the way in which they colonize forest sites and maintain site occupancy. The bud banks of the species and their potential for production of new aerial stems are significantly different. The bud bank of salmonberry must grow into a specific area. That of vine maple can appear instantaneously as a result of flattening of all or a portion of a stem by a fallen tree or other woody material.

Two recent studies (Minore and Weatherly in press; Pabst and Spies unpublished data) provided information on the occurrence of salmonberry and vine maple in

riparian areas in the Oregon Coast Range. Minore and Weatherly studied 22 riparian areas in the Oregon Coast Range and observed that these species were the most common shrubs in terms of aerial cover within 15 m of the active stream channel. Average salmonberry cover was 24, 21, and 18 percent at 5, 10, and 15 m, respectively, from the stream edge, and vine maple 14, 17, and 17 percent at the same distances. Clearly the species were important based on the aboveground space occupied by their crowns.

However, Pabst and Spies observed that, when the cover of only those plants rooted in their measurement plots was considered, a somewhat different pattern emerged than that described by Minore and Weatherly. Pabst and Spies found that the occurrence of salmonberry rooted on site was much higher close to the stream than was the cover of vine maple. In fact, vine maple was rooted on relatively drier microsites than salmonberry—sites that were more representative of upland conditions than riparian conditions.

The observations by Minore and Weatherly and Pabst and Spies can in part be explained by the clone characteristics and growth forms described earlier. Salmonberry colonization can be characterized as an active process. That is, salmonberry rhizomes must actively grow into areas adjacent to streams and be able to survive in the riparian environment. In contrast, colonization by vine maple results from a relatively passive process; for example, stems that are rooted outside of the zone influenced directly by the stream cover aerial space, or are rooted near the stream through the process of layering (fig. 5A). In these cases the stems are flattened and pinned to the substrate by fallen trees and other debris. In some cases, stems are covered by silt deposited during flooding, and rooting occurs. The debris pinning other stems to the surface may be washed away by the stream, and the possibility of rooting is temporarily eliminated.

IMPLICATIONS OF CLONE STRUCTURE TO MANAGEMENT

These two significantly different types of clone development affect the response of the species to nonchemical management practices (fig. 5). The manual cutting of salmonberry results in rapid replacement of the cut stems by sprouting from dormant buds in the bud bank located at the base of the severed stem and on the rhizome system. In most cases, the most rapid response is from the bud bank at the base of the stem. In vine maple, cutting the stems at the point of rooting can completely remove species from the immediate stream environment because basal sprouting from the original multistemmed group or those formed by layering from stems in the original group occurs outside of the riparian area. The treated clone will influence the environment adjacent to the stream only after it has grown enough to reach the stream. It would be possible to increase shade from maples over the stream by artificially pinning them down so that a portion of their crown was over the stream. Eventually, the portion of the stem that was pinned would root, and the maple stem would be anchored in the desired position.
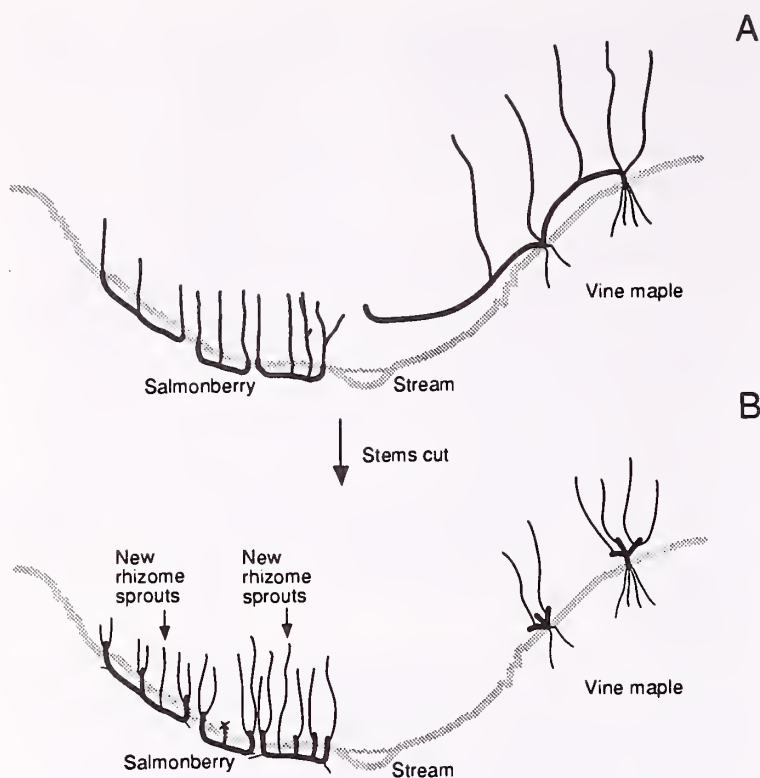
Figure 5—(A) Idealized distribution of salmonberry and vine maple clones in some riparian areas in the central Oregon Coast Range. (B) Effects of removal of aboveground stem material on presence of salmonberry and vine maple in a riparian area. Note that salmonberry stems are replaced by sprouting from the basal stem and rhizome bud banks and occupy the same area as before disturbance. Vine maple produces basal sprouts following cutting, but aerial cover is limited relative to the pretreatment condition. Only after growth of basal sprouts and subsequent pinning of the sprouts by fallen trees or other debris will this shrub again directly influence the stream.

SUMMARY

A number of shrub species in the Oregon Coast Range have the ability to form dense multiclone stands in the understory of conifer and hardwood forests after a disturbance such as forest harvesting. Although the clones of these species may be similar in aerial extent, the way in which they colonize that area may differ significantly among species. The basis for colonization and the ability to respond to disturbance lies in the growth form and growth potential of a species. We have briefly described two very different shrub growth forms and means of clone expansion and site occupancy (clone expansion through rhizome growth in the soil and subsequent ramet production in salmonberry, and clone expansion through layering of stems that are pinned to a suitable rooting media in vine maple).

The implications of these different growth forms to management of these species in riparian areas are significant. Salmonberry has the potential to recover and occupy the same physical location as the previous stand. Vine maple, on the other hand, may be removed from the immediate stream environment and only directly affect that environment after it has regrown from sites away from the stream where it is rooted.

ACKNOWLEDGMENTS

REFERENCES

Anderson, H. G. 1969. Growth form and distribution of vine maple (*Acer circinatum*) on Marys Peak, western Oregon. Ecology. 50: 127-130.

Barber, W. J. 1976. An autecological study of salmonberry in western Washington. Seattle, WA: University of Washington. 154 p. Thesis.

Burns, R. M.; Honkala, B. H. 1990. Silvics of North America. Vol. 2. Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service. 877 p.

Haeussler, S.; Coates, D.; Mather, J. 1990. Autecology of common plants in British Columbia: a literature review. FRDA Report 158. Victoria, BC: British Columbia Ministry of Forests. 272 p.

Maxwell, B. D. 1990. The population dynamics of salmonberry (*Rubus spectabilis*) and thimbleberry (*Rubus parviflorus*). Corvallis, OR: Oregon State University. 286 p. Thesis.

Minore, D.; Weatherly, H. [In press]. Trees, shrubs, and forest regeneration in riparian environments on Oregon's coastal mountains. Northwest Science.

Russel, D. W. 1973. The life history of vine maple on the H.J. Andrews Experimental Forest. Corvallis, OR: Oregon State University. 167 p. Thesis.

Tappeiner, J.; Zasada, J.; Ryan, P.; Newton, M. 1991. Salmonberry clonal and population structure: the basis for a persistent cover. Ecology. 72: 609-618.

Section 2—Classification of Riparian Communities and Grazing Effects

245

SUMMARY FLORA OF RIPARIAN SHRUB COMMUNITIES OF THE INTERMOUNTAIN REGION WITH EMPHASIS ON WILLOWS

Sherel Goodrich

ABSTRACT

Management of riparian communities depends on an understanding of at least the dominant species of plants in different riparian communities. The common plants of riparian communities are discussed briefly. Habitat, distribution, and other notes are made for 24 species of willow (Salix) *of the Intermountain region.*

RIPARIAN COMMUNITIES IN GENERAL

Common vascular plants of riparian communities of the Intermountain region are from a relatively few families. The majority of dominant woody species are in the willow (Salicaceae), birch (Betulaceae), and pine (Pinaceae) families. The majority of dominant herbaceous species are graminoid monocots (Class Liliopsida) of the sedge (Cyperaceae), rush (Juncaceae), and grass (Poaceae) families.

In the willow family are poplars, cottonwoods, and aspen (*Populus*) and willows (*Salix*). Fremont cottonwood (*Populus fremontii* Wats.) and other native cottonwoods are common along major rivers and streams at lower elevations (mostly below the zone of coniferous trees). Narrowleaf cottonwood (*Populus angustifolia* James) is common along streams and rivers often in canyons and extending upward into the coniferous tree zone. *Populus acuminata* Rydb. (a hybrid of narrowleaf cottonwood and wide-leaf cottonwoods) is sometimes found at the mouth of canyons at elevations intermediate to that of the parent species. The native willow trees Gooding willow (*S. gooddingii* Ball), and red willow (*S. laevigata* Bebb.) are mostly limited to the southern part of the area, but peachleaf willow (*S. amygdaloides* Andress.), a small tree, is widespread in the region. Crack willow (*S. fragilis* L.) is introduced and naturalized along riparian areas in much of the region. Other introduced tree willows are commonly planted.

All the members of the birch family in the Intermountain region are known from riparian areas. Thinleaf alder (*Alnus incana* [L.] Moench) and water birch (*Betula occidentalis* Hook.) have been identified as indicators of specific riparian community types (Manning and Padgett in preparation; Padgett and others 1989). Coniferous trees of family Pinaceae are common in montane riparian areas.

Boxelder (*Acer negundo* L.) of Aceraceae is the only tree species recognized by Padgett and others (1989) as an indicator of tree-dominated riparian communities that does not belong to the three families listed above.

The nine genera of the sedge family known to the region (Cronquist and others 1977; Welsh and others 1987) all have species that occur in riparian areas. Several species of bullrush (*Scripus*) are common to dominant in wet bottomlands where they are often associated with cattail (*Typha* spp.) of Typhaceae. Deerhair bullrush (*Scripus caespitosus* L.) and cotton grass (*Eriophorum* spp.) are species of wet and boggy meadows at subalpine elevations. Many species of sedge (*Carex*), one of the largest genera of the region, and spikerush (*Eleocharis*) grow in riparian areas over a wide elevational range. Twelve sedges and two spikerushes were recognized by Padgett and others (1989), Manning and Padgett (in preparation), and Youngblood and others (1985) as indicators of herbaceous riparian community types.

Although the rush family is well represented in number of species common in riparian areas, only wiregrass or baltic rush (*Juncus balticus* Willd.) was recognized by Padgett and others (1989) and Youngblood and others (1985) to indicate a specific riparian community type.

The grass family is represented in riparian areas by numerous species. Compared to the sedge family, more of the grasses are generalists. Relatively few have been found to be specific indicators of riparian community types. These include redtop (*Agrostis stolonifera* L.), bluejoint (*Calamagrostis canadensis* [Michx.] Beauv.), tufted hairgrass (*Deschampsia cespitosa* [L.] Beauv.), timber oatgrass (*Danthonia intermedia* Vasey), meadow barley (*Hordeum brachyantherum* Nevski), and Nevada bluegrass (*Poa nevadensis* Vasey). Kentucky bluegrass (*Poa pratensis* L.) is often used as an indicator of disturbed riparian communities (Manning and Padgett in preparation; Padgett and others 1989; Youngblood and others 1985).

Species of herbaceous dicots (class Magnoliopsida) are numerous, but relatively few are dominant and consistent enough in riparian areas to be considered indicators of riparian community types. Marshmarigold (*Caltha leptosepala* DC.), Jeffery shooting star (*Dodecatheon jeffreyi* van Houtte), cow parsnip (*Heracleum lanatum* Michx.), western blue flag (*Iris missourinesis* Nutt.), bigleaf lupine (*Lupinus polyphyllus* Lindl.), streamside bluebells (*Mertensia ciliata* [Jones] G. Don.), arrowleaf groundsel (*Senecio triangularis* Hook.), and skunk cabbage or false hellebore (*Veratrum californicum* Dur.), are among the few that have been used to identify riparian community types. Field horsetail (*Equisetum arvense* L.) of Division Equisetophyta

is a another widely distributed forb that is an indicator (Manning and Padgett in preparation; Padgett and others 1989) of riparian conditions.

RIPARIAN SHRUB COMMUNITIES

Woody species outside the families listed above that have been recognized as indicators of riparian shrub community types in the Intermountain region include red-osier dogwood (*Cornus sericea* L.) of the dogwood family (Cornaceae), shrubby cinquefoil (*Potentilla fruticosa* L.), chokecherry (*Prunus virginiana* L.), and woods rose (*Rosá woodsii* Lindl.) of the rose family (Rosaceae), alder buckthorn (*Rhamnus alnifolia* L'Her.) of the buckthorn family (Rhamnaceae), wild black current (*Ribes hudsonianum* Richards) of the current family (Grossulariaceae), skunkbush (*Rhus aromatica* Ait.) of the sumac family (Anacardiaceae), and silver sagebrush (*Artemisia cana* Pursh) of the sunflower family (Asteraceae).

Several species of willow are consistently dominant enough to be considered indicators of riparian community types. Willow community types have been refined by using dominant understory species as indicators. These understory indicators include the following sedges: beaked sedge (*Carex rostrata* Stokes), Nebraska sedge (*C. nebraskensis* Dewey), Rocky Mountain sedge (*C. scopulorum* T. H. Holm.), water sedge (*Carex aquatilis* Wahl.), the following grasses: bluejoint, fowl bluegrass (*Poa palustris* L.), Kentucky bluegrass, mountain brome (*Bromus carinatus* Hook. & Arn.), sheep fescue (*Festuca ovina* L.), and tufted hairgrass; the following forbs: cow parsnip, field horsetail, gray ligusticum (*Ligusticum grayi* Coult. & Rose), starry false solomon seal (*Smilicina stellata* [L.] Desf.), and sweetscented bedstraw (*Galium triflorum* Michx.) (Manning and Padgett in preparation; Padgett and others 1989; Youngblood and others 1985).

With willow species dominating so many riparian shrub communities, the following expanded treatment of the shrubby members of this genus seems appropriate for this paper. Keys and descriptions to species are not provided in this paper. These are provided in floras of the region, including Cronquist and others (1972, 1977, 1984), Davis (1952), Dorn (1977a), Kartez (1987), and Welsh and others (1987). Treatments specifically for willows include Brunsfeld and Johnson (1985); Dorn (1977b); Goodrich (1983); Goodrich (1992); Padgett and Goodrich (in press). Arctic willow (*Salix arctica* Pallas), Cascade willow (*S. cascadensis* Cockerell), least willow (*S. rotundifolia* Trautv.), and netleaf willow (*S. reticulata* L.) are creeping, matted shrubs mostly of alpine areas, and these are not treated below.

LOW WILLOWS

Low willows are separated from tall willows for a number of management considerations. Low willows as a group indicate higher elevations than the tall willow group. Difference in elevation can have a strong bearing on management decisions. Tall willows provide both forage and cover for big game animals including moose, and while low willows provide forage, they are not nearly as effective in providing hiding cover.

BARCLAY WILLOW (*Salix barclayi* Anderss.). **Habit:** Shrub to 3 (3.5) m tall with several stems from a root crown.

Habitat: Most commonly in streamside openings in bottomland of spruce-fir and lodgepole pine forests and cold air drainages down into the upper Douglas-fir zone on moist gravelly soils that often have an organic or silty mantle up to several decimeters thick (Brunsfeld and Johnson 1985), mountain slopes, streambanks, and swamps (Dorn 1977b). **Intermountain Distribution:** Idaho, northwest Wyoming. **Community Dominance:** Apparently dominant at least on some sites within its limited range in the region.

BARRENGROUND WILLOW, SHORT-FRUITED WILLOW (*Salix brachycarpa* Nutt. var. *brachycarpa*). **Habit:** Shrub (0.25) 0.6-1.5 m tall with several to many stems from a root crown. **Habitat:** From exposed well-drained slopes and ridges to moist and wet shaded sites, mostly aspen and Douglas-fir zones to alpine, but known from Wyoming big sagebrush zone in Idaho (Brunsfeld and Johnson 1985). Mostly on basic substrates in Utah (Goodrich 1983). This taxon is one of the few willows, including coyote willow (*S. exigua*), that occur on alkaline or saline habitats. It occurs on serpentine barrens, salt marshes, alkaline meadows, hydromagniesite swamps, salt flats, and cones of mineral springs. However, it is not restricted to these habitats, and occurs on a wide range of sites including open woodlands, bogs, muskegs, meadows, streambanks, alpine slopes, unstable scree slopes, and morains. It seems particularly adapted to habitats that experience repeated severe disturbances (Argus 1965). **Intermountain Distribution:** Mostly eastern Idaho; western Wyoming; scattered in mountains and plateaus in most of Utah; apparently lacking in Nevada. **Community Dominance:** This is not recognized in the region as an indicator of riparian community types. Perhaps there are areas where it is a dominant riparian species, especially below National Forest System lands where most published community type classifications reviewed for this paper were conducted. It is a dominant in some upland communities on limestone in the Uinta Mountains. **Other Notes:** Arctic plants of another variety are smaller. The taller plants of the Intermountain region (var. *brachycarpa*) are often equal in stature to plants of glaucous willow (*S. glauca*). These two are often confused in the region.

HORRY WILLOW (*Salix candida* Fluegge). **Habit:** Shrub (0.2) 0.5-1.2 (1.5) m tall with several stems from a root crown. **Habitat:** Bogs (Dorn 1977b), bogs and swamps (Hitchcock and Cronquist 1973), mostly on hummocks of wet, quaking swamp/meadows or fens on soils with a layer of peat 1 dm or more thick overlying wet silty muck more than 1 m deep (Brunsfeld and Johnson 1985). **Intermountain Distribution:** East-central Idaho (Brunsfeld and Johnson 1985), Freemont County, Idaho (Dorn 1977b). **Community Dominance:** Distribution and abundance in the region are probably not extensive enough to understand capacity for dominance. It is seldom collected in the Pacific Northwest (Hitchcock and Cronquist 1973). It is listed as occasional for Alaska (Welsh 1974). **Other Notes:** Habitat outside Intermountain region: wet, usually alkaline fens and thickets at edges of ponds and on river terraces (Welsh 1974).

UNDERGREEN WILLOW, VARIABLE WILLOW (*Salix commutata* Bebb.). **Habit:** Shrub to 3 m tall with several to many stems from a root crown. **Habitat:** Known in east-central Idaho in perennially moist habitats within

subalpine forests of lodgepole pine, Engelmann spruce, and subalpine fir, mostly in low willow and sedge meadows with highly organic soils adjacent to lakes, streams, and springs (Brunsfeld and Johnson 1985). **Intermountain Distribution:** Central and southeastern Idaho. References to this species in Wyoming have been based on specimens of Eastwood willow (*S. eastwoodiae*) (Dorn 1977b). References for Utah are perhaps based on specimens of Wolf willow (*S. wolfii*) (Goodrich 1983). **Community Dominance:** Distribution and abundance in the region are probably not extensive enough to understand capacity for dominance. **Other Notes:** In Alaska this is known as an early seral species on glacial moraine and rocky slopes of alpine tundra and on gravelly benches along rivers as well as of willow thickets and wet fens (Welsh 1974).

EASTWOOD WILLOW (*Salix eastwoodiae* Cockerell ex Heller). **Habit:** Shrub to 4 m tall with few to many stems from a root crown. **Habitat:** Open streambottoms and lake edges in moist, but well-drained and often gravelly soils, often intermingled with or adjacent to low-lying sites with more saturated soils dominated by plainleaf willow (*S. planifolia*) and sedges at subalpine habitats (Brunsfeld and Johnson 1985). **Intermountain Distribution:** Idaho including Salmon River Range and Sawtooth Mountains, western Wyoming, northern and western Nevada, not known from Utah. **Community Dominance:** Manning and Padgett (in preparation) recognized a community type in Nevada for which this species is the dominant. One of the most common willows in the Sierra Nevada forming low thickets (Kartesz 1987).

FARR WILLOW (*Salix farriae* Ball). **Habit:** Shrub to 1.5 (2) m tall with several to many stems from a root crown. **Habitat:** Known from shallow, highly organic soils at subalpine and timberline elevations (Brunsfeld and Johnson 1985), and meadows and streambanks in mountains (Dorn 1977a). **Intermountain Distribution:** Known from three sites in Idaho from the head of the West Fork of the Pahsimeroi River, Lost River Range and upper Slate Creek, White Cloud Peaks (Brunsfeld and Johnson 1985) and Yellowstone Park and Wind River Mountains in northwestern Wyoming. **Community Dominance:** Distribution and abundance in the region are not extensive enough to understand capacity for dominance.

GLAUCOUS WILLOW, GRAYLEAF WILLOW (*Salix glauca* L.). **Habit:** Shrub (0.1) 0.3-1 (3) m tall with several to many stems from a root crown. **Habitat:** Exposed, well-drained alpine slopes, ridges, and moraines, and in wet places mostly from spruce-fir and alpine zones, often with krummholtz Engelmann spruce in the Uinta Mountains. **Intermountain Distribution:** Common across the Uinta Mountains of Utah, at isolated stations in the Wasatch Mountains, and at Horseshoe Flat of the Wasatch Plateau in Utah, known in Idaho only from near Henry's Lake (Cronquist in preparation) and western Wyoming, not known from Nevada where specimens of *S. orestera* have been mistaken as *S. glauca*. **Community Dominance:** A dominant shrub over much area in alpine basins, slopes, and ridges in the Uinta Mountains. Padgett and others (1989) described one riparian community type from these mountains that is dominated by this species. It also dominates upland communities on inceptisols that are probably not riparian. In some communities the overstory of this species is dense enough to allow for only a sparse understory.

Other Notes: On exposed ridges at high elevations, plants are often less than 0.3 m tall. Such plants are often misidentified as barrenground willow.

ORESTERA WILLOW (*Salix orestera* Schneider). **Habit:** Shrub to 3 m tall with few to many stems from a root crown. **Habitat:** Streambanks and wet meadows and occasionally on exposed well-drained slopes. **Intermountain Distribution:** Nevada in Ruby Mountains (Lewis 1971), Wheeler Peak of Snake Range (Lewis 1973), Toiyabe Range (Goodrich 1981), eastern Sierra Nevada Mountains of western Nevada and White Pine Mountains (Kartesz 1987). **Community Dominance:** Manning and Padgett (in preparation) have described one community type in which this is the dominant overstory species. **Other Notes:** This species is closely related to grayleaf willow and occurs on similar habitats.

PLAINLEAF WILLOW (*Salix planifolia* Pursh). **Habit:** Shrub 0.5-1.5 (4) m tall, with numerous stems from a root crown. **Habitat:** Streamside and wet meadow communities, often in cold-air drainage basins with water table at or near the surface for most or all of the growing season, on Histosols, Aquic Cryoborolls, Aquic Cryaquepts, and related soils (Padgett and others 1989), in the spruce-fir and alpine zones and at lower elevations in valley bottoms where there is significant cold air pooling (Brunsfeld and Johnson 1985). **Intermountain Distribution:** Wyoming (mostly Wind River and Teton Mountains), Idaho, common across the Uinta Mountains, and at isolated locations in the Wasatch Mountains, and Utah Plateaus Section of Utah, known in Nevada only from Robinson Lake, Elko County (Kartesz 1987). **Community Dominance:** Four riparian community types have been described by Padgett and others (1989) and Manning and Padgett (in preparation) in which this is the dominant overstory species. Even where the overstory of this species is quite dense, there is usually still a well-developed understory of graminoids and forbs. **Other Notes:** The above discussion applies mostly to var. *monica* (Bebb) Jepson. Variety *planifolia* (discussed under tall willows later) is of lower elevations and is commonly 2-4 m tall. The differences might be more a function of habitat than of genetics.

TWEEDY WILLOW (*Salix tweedyi* [Bebb] Ball). **Habit:** Shrub to 3 (4) m tall, with several stems from a root crown. **Habitat:** Steamside, lakeside, and wet meadow communities in the subalpine zone and following cold-air drainage down into the Douglas-fir zone in Engelmann spruce-dominated streambottoms (Brunsfeld and Johnson 1985), probably not above timberline (Hitchcock and Cronquist 1973). **Intermountain Distribution:** Wind River and Teton Mountains of Wyoming and central Idaho. **Community Dominance:** Present but not abundant in any of six drainages in east-central Idaho (Brunsfeld and Johnson 1985). Rare except in Big Horn Mountains of Wyoming (Hitchcock and Cronquist 1973).

WOLF WILLOW (*Salix wolfii* Bebb in Rothr.). **Habit:** 0.6-1.5 (2) m tall with several to many stems from a root crown. **Habitat:** Streamside and wet meadow communities from aspen and spruce-fir zones. In east-central Idaho the habitat varies from relatively wet sites (especially at lower elevations) to relatively dry sites (especially at higher elevations) where it inhabits soils that are well drained, or at least well aerated, and often of sandy texture (Brunsfeld and Johnson 1985). **Intermountain Distribution:**

Northwestern Wyoming, across central Idaho, Elko County (Ruby Mountains) in Nevada, and Uinta Mountains, Bear River Range, and Scad Valley of the Wasatch Plateau in Utah. **Community Dominance:** Eight riparian community types have been described by Manning and Padgett (in preparation), Padgett and others (1989), and Youngblood and others (1985) in which this is the dominant overstory species. **Other Notes:** Two varieties are recognized for the region. Variety *wolfii* with mostly glabrous capsules is chiefly southern, occurring mainly in Colorado, northeastern Utah, and Wyoming, barely entering southwestern Montana. Variety *idahoensis* Ball, with hairy capsules, is more northern and western, occurring in northwestern Wyoming and adjacent Montana, across central Idaho to the Wallowa Mountains of Oregon and Elko County, Nevada (Cronquist in preparation).

TALL SHRUB WILLOWS

ARROYO WILLOW (*Salix lasiolepis* Benth.). **Habit:** Shrub or small tree, 2-6 m tall, with several stems from a root crown. **Habitat:** Along streams, from desert shrub through pinyon-juniper, and into lower aspen. **Intermountain Distribution:** Widespread in the Great Basin of Utah and Nevada and in the Virgin River drainage of Utah. This is the dominant willow of the Spring Mountains in southern Nevada where the only other willow known is coyote willow (Manning and Padgett in preparation). **Community Dominance:** Three riparian community types are described by Padgett and others (1989) and Manning and Padgett (in preparation) in which this is the dominant overstory species.

BEBB WILLOW (*Salix bebbiana* Sarg.). **Habit:** Tall shrub or small tree, (2) 4-6 (8) m tall, with few main stems from a root crown, the larger stems to 20 cm thick. **Habitat:** Seeps, springs, riparian areas, often with other willows, alder, birch, and aspen, present but seldom abundant in the Wyoming big sagebrush zone in Idaho (Brunsfeld and Johnson 1985), most common in the mountain big sagebrush, aspen, and Douglas-fir zones. **Intermountain Distribution:** Scattered in much of Idaho, Wyoming, and Utah, known in Nevada only from Elko, Lander, and White Pine Counties. **Community Dominance:** Widespread, but seldom a dominant species. Padgett and others (1989) recognized one riparian community type in which this is the dominant species. They recognized this as a minor type found in the Canyonlands and adjacent floristic sections of Utah. **Other Notes:** Larger specimens in open meadows often show conspicuous hedging within the reach of browsing animals.

BOOTH WILLOW (*Salix boothii* Dorn). **Habit:** Medium shrub, (1.5) 2-4 (6) m tall, commonly with numerous stems from a root crown, the stems seldom over 5 cm thick. **Habitat:** Streamside and wet meadow communities on a variety of soils and over a wide range of riparian sites from rocky or gravelly ones near the water table to drier benches with deep fine-textured soils (Brunsfeld and Johnson 1985), mostly in the mountain big sagebrush, aspen, Douglas-fir, and lower subalpine zones. **Intermountain Distribution:** Common in western Wyoming, Idaho, northern Nevada, and northern Utah. Limited in southern Utah to the Utah Plateaus Section. **Community Dominance:** This willow is often a community dominant. Nine riparian community

types dominated by this species have been described for Utah and southeastern Idaho (Padgett and others 1989). **Other Notes:** Problems in nomenclature of this taxon include an array of misapplied names and inadequately typified synonyms.

DRUMMOND WILLOW (*Salix drummondiana* Barratt ex Hook.). **Habit:** Medium to tall shrubs, (1) 2-4 (6) m tall, with numerous stems from a root crown. **Habitat:** Common to dominant on steep gradient, stony-lined streams in substrates that resist weathering such as quartzite and some types of granite and in water-fed boulder fields of similar substrate within the zones of Engelmann spruce, subalpine fir, and lodgepole pine forests. Often with Booth willow and less commonly with Geyer willow (*S. geyeriana*) in less stony areas at the lower part of its elevational range. **Intermountain Distribution:** Common in montane parts of Wyoming, Idaho, Utah, and northern two-thirds of Nevada. **Community Dominance:** Dominant as described above in stony habitats in the subalpine zone. **Other Notes:** Plants of the species sprout vigorously; shoots of the season are often over 1 m in length. This species was not used to describe any specific community types by Padgett and others (1989) or Youngblood and others (1985). The dominance of this species and absence of Booth willow in high-elevation stony-lined (quartzite) streams of the Uinta Mountains indicates a need to describe one or more riparian community types in which this species is the dominant shrub.

COYOTE WILLOW, SANDBAR WILLOW, NARROW-LEAF WILLOW, DUSKY WILLOW (*Salix exigua* Nutt.). **Habit:** Medium shrub, (1) 2-5 (8) m tall, strongly colonial with individual stems arising singly or few together from running roots similar to aspen (unique in this respect from other willows of the region). **Habitat:** Moist to wet places from desert shrub and Wyoming big sagebrush zones through the pinyon-juniper zone and less common into the aspen and lower Douglas-fir zones. **Intermountain Distribution:** In every county of Nevada (Kartesz 1987), every county in Utah (Goodrich 1983), probably in all counties of Wyoming and Idaho within the Intermountain region. **Community Dominance:** With a colonial habit, this species is strongly competitive and dominant in many areas. Seven riparian community types have been described for the region by Manning and Padgett (in preparation), Padgett and others (1989), and Youngblood and others (1985). **Other Notes:** See Brunsfeld and Johnson (1985) for a discussion of the taxa within this complex. Unusually tall (perhaps exceeding 8 m) colonies at isolated stations in central Nevada are strikingly different, but other than stature and diameter of stems, they are like colonies at other nearby sites.

FALSE MOUNTAIN WILLOW (*Salix pseudomonticola* Ball). **Habit:** Shrub (1-2 m in quaking, hummocky meadows) 4-5 (6) m tall, with many stems from a root crown. **Habitat:** Quaking, hummocky meadows but more commonly in more mesic sites. **Intermountain Distribution:** Known from two locations in east-central Idaho (Brunsfeld and Johnson 1985). Apparently limited in the region to east-central Idaho. **Community Dominance:** Importance of this feature in the region is limited by the limited distribution.

GEYER WILLOW (*Salix geyeriana* Anderss.). **Habit:** Medium shrub, (1) 1.5-4.5 m tall, with numerous stems

from a root crown. **Habitat:** Moist and wet meadows and along low-gradient, meandering streams through open meadows, on soils with high percent clay or silt. The habitat description provided by Brunsfeld and Johnson (1985) for east-central Idaho seems appropriate for other parts of the region except for elevational zones. Part of their description follows:

> The distribution ranges from the upper part of the Wyoming big sagebrush zone to the upper Douglas-fir or middle mountain big sagebrush zone. It is absent from lower elevation riparian communities and is rare in the subalpine zone. It is typically found in drier parts of the riparian zone, often on benches well above the stream level. These sites generally have deep, predominately fine-textured soils, and lack an overstory or have only a light overstory of water birch, thin-leaf alder, or lodgepole pine. The species is less abundant or absent on moister sites. Thus it is generally not well represented within its elevational limits along steep gradient streams which often have a moist, narrow riparian strip. Only at its lower elevational limits does it inhabit notably wet, fine-textured soils. Geyer willow is generally confined in any one drainage to a stream segment spanning less than 610 vertical m (2000 ft). Booth willow is a constant associate of Geyer willow, but differs in reaching its greatest abundance in moist streamside habitats and in being less abundant on drier, Geyer willow-dominated sites.

With minor exceptions this habitat description applies well in other parts of the region. One exception is to be expected with lower latitudes. Geyer willow apparently is absent from the Wyoming big sagebrush zone in Utah where it is most common in the aspen, mountain big sagebrush, and lower spruce-fir and lodgepole pine zones. Also Booth willow is not a constant associate at the margins of its range and of course not beyond its range. **Intermountain Distribution:** Common in western Wyoming except perhaps in the Salt Range of Lincoln County, across Idaho, Uinta, Wasatch, Bear River Mountains and Utah Plateaus Section of Utah, mostly isolated in the Ruby Mountains, Santa Rosa, and Toiyabe Ranges of Nevada. **Community Dominance:** Eight riparian community types have been described by Padgett and others (1989) and Youngblood and others (1985). The species has strong capacity to dominate in its preferred ecological range. **Other Notes:** In boggy meadows, plants of the species are often depauperate and take on the stature of the low willows. In preference of habitat this species is the opposite of Drummond willow, which is common to dominant on steep-gradient, stoney-lined, often narrow, streams that are often closely bordered by or shaded by trees. However, the preference of habitat does not prohibit the two from occasionally growing together.

JEPSON WILLOW (*Salix jepsonii* Schneid.). **Habit:** Shrub, 1-3 m tall. **Habitat:** Streambanks, lake shores, and moist open slopes in red fir to subalpine fir zones. **Intermountain Distribution:** Carson sink area, Churchill County and Galena Creek, Washoe County, Nevada (Kartesz 1987); Steens Mountains (Cronquist in preparation). **Community Dominance:** Unknown.

LEMMON WILLOW (*Salix lemmonii* Bebb in Wats.). **Habit:** Shrub 1-3 (5) m tall, with many stems from a root crown. **Habitat:** Streambanks, from the base of mountains to moderately well up in the mountains (Cronquist in preparation). Foothills to mountains, often in the yellowpine zone (Kartesz 1987). For east-central Idaho, Brunsfeld and Johnson (1985) have described the habitat in some detail as follows:

It occurs...from the upper part of the Douglas-fir zone to the lower subalpine zone. Like *S. geyeriana*, it inhabits relatively dry portions of the riparian zone, but, within a given drainage, it always grows at higher elevations than Geyer willow. Most of its habitats are frosty bottomlands dominated by mountain big sagebrush or forest of lodgepole pine. Soil comparisons showed *Salix lemmonii* to be growing in well-drained gravelly or sandy soils....

Intermountain Distribution: Idaho and northern and western (Sierra Nevada Mountains) Nevada. **Community Dominance:** Manning and Padgett (in preparation) have described six riparian community types for which this is the dominant overstory species. The plant forms dense thickets often covering large areas (Kartesz 1987).

MOUNTAIN WILLOW (*Salix monticola* Bebb in Coult.). **Habit:** Shrub 1.5-4 m tall, with numerous stems from a root crown. **Habitat:** Streambanks and wet meadows from the plains near mountains to subalpine (Dorn 1977b). **Intermountain Distribution:** Perhaps limited in the region to the LaSal and Abajo Mountains of Utah. **Community Dominance:** Too little is known about the species in the region to discuss its capacity for dominance. However, in Colorado where the species is quite common, it appears similar to Booth willow in habit, habitat, and capacity for dominance. **Other Notes:** Specimens of Booth willow and false mountain willow have been mistaken for this species in the region.

PLAINLEAF WILLOW (*Salix planifolia* Pursh var. *planifolia*). **Habit:** Shrub (1) 2-4 m tall, with numerous stems from a root crown. **Habitat:** Riparian areas at lower elevations than var. *monica* as discussed earlier. Most common in and below the Douglas-fir or lower spruce-fir zones. Mostly with tall willows such as Booth willow and Geyer willow. **Intermountain Distribution:** Isolated stations in Idaho, Wyoming, western Nevada, and probably limited in Utah to the Uinta Mountains and perhaps Fishlake Plateau. **Community Dominance:** Importance of community dominance in the region is limited by the isolated and limited distribution. **Other Notes:** See also the discussion of *S. planifolia* var. *monica* earlier.

SCOULER WILLOW (*Salix scouleriana* Barratt ex Hook.). **Habit:** Shrub or small tree, 3-10 (15) m tall, with few to several stems up to 10 (20) cm thick near the base, these from a large root crown. **Habitat:** Occasionally in riparian areas and more common in upland areas above riparian habitats on well-drained slopes with aspen and coniferous trees. This willow occurs in about 25 forest habitat types of central idaho. These types are in the Douglas-fir, Grand Fir, and Subalpine Fir Series but not in the Ponderosa Pine Series (Brunsfeld and Johnson 1985; Steele and others 1981). **Intermountain Distribution:** Widely distributed in the region except in southern Nevada. **Community Dominance:** This species is an associate with alder, birch, aspen, coniferous trees, and other willows. Rarely, if ever, is it a dominant species. **Other Notes:** Scouler willow is noted for its ability to rapidly colonize burned and logged areas in coniferous and aspen forests (Davis 1952).

WHIPLASH WILLOW (*Salix lucida* Muhl. ssp. *caudata* [Nutt.] Argus). **Habit:** Tall shrub or small tree, with several to many stems arising from a large root crown, the larger stems 10-30 (47) cm in diameter. **Habitat:** Riparian areas from Wyoming big sagebrush to aspen and Douglas-fir

zones. In east-central Idaho, this willow usually grows in moist, sandy or gravelly soils, so it is frequently found close to the stream edge of the high-water line on greatly fluctuating streams. **Intermountain Distribution:** Across Idaho, western Wyoming, and Utah but infrequent in the western one-fourth and southern one-fourth of the State, mostly limited to northern and western Nevada. **Community Dominance:** Areas of dominance are mostly small. This is the dominant overstory species in two riparian community types recognized by Manning and Padgett (in preparation). **Other Notes:** Synonymy includes: *S. lasiandra* var. *caudata* (Nutt.) Sudw. and *S. caudata* (Nutt.) Heller.

YELLOW WILLOW (*Salix lutea* Nutt.). **Habit:** Shrub (2) 3-5 (9) m tall, occasionally treelike with stems to 20 cm thick, with numerous stems from a large root crown. **Habitat:** Along streams and ditches in valleys and lower canyons and about seeps and springs on hillsides, common from Wyoming big sagebrush through pinyon-juniper and infrequently into aspen and lower Douglas-fir zones. **Intermountain Distribution:** Across much of Idaho, Wyoming, and Utah, and northern and central Nevada. **Community Dominance:** This is a major component of riparian vegetation at elevations of 1,520-1,830 m (5,000-6,000 ft) in east-central Idaho (Brunsfeld and Johnson 1985). In Utah, the species is mostly found below elevations included in National Forest System lands, and thus was not included as a dominant species by Padgett and others (1989). However, it is a dominant overstory species in open valleys and canyons at lower elevations in Utah. In Nevada where National Forest System lands include more of the habitat of this species, Manning and Padgett (in preparation) described five riparian community types in which this is the dominant overstory species. **Other Notes:** Floral features are nearly identical to those of Booth willow. The two species overlap slightly in habitat with yellow willow mostly growing at lower elevations than Booth willow. The glaucous lower surface of leaves and ashy-gray bark of older twigs of yellow willow are principal distinguishing features that separate these two species.

REFERENCES

Argus, George W. 1965. The taxonomy of the *Salix glauca* complex in N. America. Contributions from the Gray Herbarium of Harvard University. CXCVI:1-142.

Brunsfeld, Steven J.; Johnson, Frederic D. 1985. Field guide to the willows of east-central Idaho. Bull. 39. Moscow, ID: University of Idaho. 95 p.

Cronquist, Arthur. [In preparation]. *Salix*. Intermountain flora Vol. 2.

Cronquist, Arthur; Holmgren, Arthur H.; Holmgren, Noel H.; Reveal, James L. 1972. Intermountain flora. Vol. 1. New York: Hafner. 270 p.

Cronquist, Arthur; Holmgren, Arthur H.; Holmgren, Noel H.; Reveal, James L.; Holmgren, Patricia K. 1977. Intermountain flora. Vol. 6. New York: Columbia University Press. 584 p.

Cronquist, Arthur; Holmgren, Arthur H.; Holmgren, Noel H.; Reveal, James L.; Holmgren, Patricia K. 1984. Intermountain flora. Vol. 4. Bronx, NY: New York Botanical Garden. 573 p.

Davis, Ray J. 1952. Flora of Idaho. Dubuque, Iowa: W. C. Brown. 828 p.

Dorn, Robert D. 1977a. Manual of the vascular plants of Wyoming. Vols. 1 and 2. New York: Garland Publishing. 1998 p.

Dorn, Robert D. 1977b. Willows of the Rocky Mountain States. Rhodora. 79: 390-429.

Goodrich, Sherel. 1981. A floristic study of central Nevada. Provo, UT: Brigham Young University. 400 p. Thesis.

Goodrich, Sherel. 1983. Utah flora: Salicaceae. Great Basin Naturalist. 43(4): 531-550.

Goodrich, Sherel. 1992. Field key to *Salix* of Utah based on vegetative features. In: Landis, Thomas D., tech. coord. Proceedings—Intermountain Forest Nursery Association annual meeting; 1991 August 12-16; Park City, UT. Gen. Tech. Rep. RM-211. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 71-73.

Hitchcock, C. Leo; Cronquist, Arthur. 1973. Flora of the Pacific Northwest. Seattle, WA: University of Washington Press. 730 p.

Kartesz, John Thomas. 1987. A flora of Nevada. Reno, NV: University of Nevada. 1729 p. Dissertation.

Lewis, Mont E. 1971. Flora and major plant communities of the Ruby-East Humboldt Mountains. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 62 p.

Lewis, Mont E. 1973. Wheeler Peak area. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 17 p.

Manning, Mary E.; Padgett, Wayne G. [In preparation]. Riparian community type classification of Nevada. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region.

Padgett, Wayne G.; Youngblood, Andrew P.; Winward, Alma H. 1989. Riparian community type classification of Utah and southeastern Idaho. R4-Ecol-89-01. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 191 p.

Padgett, Wayne G.; Goodrich, Sherel. [In press]. In: Proceedings 6th Utah Shrub Ecology workshop; 1990 July 17-18; Price, UT. Logan, UT: Utah State University, College of Natural Resources.

Steele, Robert; Pfister, Robert D.; Ryker, Russell A.; Kittams, Jay A. 1981. Forest habitat types of central Idaho. Gen. Tech. Rep. INT-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 138 p.

Welsh, Stanley L. 1974. Anderson's flora of Alaska and adjacent parts of Canada. Provo, UT: Brigham Young University Press. 724 p.

Welsh, Stanley L.; Atwood, N. Duane; Goodrich, Sherel; Higgins, Larry C. 1987. A Utah flora. Great Basin Naturalist Memoirs. 9: 1-984.

Youngblood, Andrew P.; Padgett, Wayne G.; Winward, Alma H. 1985. Riparian community type classification of eastern Idaho-western Wyoming. R4-Ecol-85-01. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 78 p.

245

CLASSIFICATION AND MANAGEMENT OF RIPARIAN-WETLAND SHRUB SITES IN MONTANA

Paul L. Hansen

ABSTRACT

A classification system with management information was developed for riparian-wetland sites in Montana. Concepts and terminology were consistent with usage proposed by Daubenmire and used in numerous studies of vegetation-based ecological site classification (habitat type classification system). In addition, we identified and described several major seral plant communities (community types) that are stable for time frames important for land management decisions. Thirty-two riparian-wetland shrub communities were identified with 16 representing habitat types and 16 representing community types.

INTRODUCTION

Although the land area is small, riparian-wetland areas occupy a unique position in the landscape and life of the West with their importance far exceeding their total area. Riparian-wetland areas are defined as the green zones associated with lakes, reservoirs, estuaries, potholes, springs, bogs, fens, wet meadows, and ephemeral, intermittent, or perennial streams. The riparian-wetland zone occurs between the upland or terrestrial zone and the aquatic or deep-water zone. Riparian-wetland areas are important islands of diversity within extensive upland ecosystems. Abundant water, forage, and habitat attract a proportionately greater amount of use and conflict than their small area would indicate. They are of prime importance to water quality, water quantity, stream stability, and fisheries habitat. They are vital to the livestock grazing industry and many are also well suited for development as high-quality agricultural farmland. In addition, many riparian-wetland sites are excellent timber-producing sites. Most sites provide critical habitat needs for many species, and they support a greater concentration of wildlife species and activities than any other type of location on the landscape. In addition, riparian-wetland areas can be considered the "threads" that tie together all the other ecosystems. The importance of these areas as wildlife corridors cannot be emphasized enough.

In contrast to their importance, riparian-wetland communities are among the least studied and least understood areas in terms of structure, function, and management. The riparian-wetland zone has often been overlooked, ignored, or considered a minor inclusion of the larger terrestrial or aquatic systems. Impacts from excessive grazing, timber harvesting, road construction, and agriculture may drastically affect these communities. Management of riparian-wetland areas has become a major issue during the past decade and will continue to be a major issue during the 1990's. Multiresource opportunities, multidisciplinary concerns, and multiownership patterns call for a high level of coordination and cooperation to meet social needs.

OBJECTIVES

A classification system with resource management information was developed for all riparian-wetland sites in Montana (Hansen and others 1991). Concepts and terminology were consistent with usage proposed by Daubenmire and used in numerous studies of vegetation-based ecological site classification (habitat type classification system). In addition, we identified and described several major seral plant communities (community types) that are stable for time frames important for land management decisions. A total of 103 habitat types and community types were identified. This included tree, shrub, graminoid, and forb "types." Of these, 32 riparian-wetland shrub communities were identified with 16 representing habitat types and 16 representing community types. The following information was discussed for each "type": (1) number of stands sampled, (2) location and associated riparian-wetland landforms, (3) floristic characteristics of climax stands and disturbed stands, (4) seral stages (habitat types only), (5) potential natural community (community types only), (6) soils, (7) adjacent communities (including both wetter and drier), (8) livestock management, (9) wildlife management, (10) fisheries management, (11) fire management, (12) soil management and rehabilitation opportunities, (13) recreational uses and considerations, (14) similarities to other classification systems (for example, USDI Fish and Wildlife Service wetland classification system and USDA Soil Conservation Service range site classification system), and (15) relationship to other studies.

FIELD METHODS

Stand selection was based on "subjective sampling without preconceived bias" as described by Mueller-Dombois and Ellenberg (1974). Plots were selected that reflect the apparent range of environmental and successional conditions of the area and homogeneity of the vegetation, rather than the eventual placement of the stand within a classification system.

Studies in the northern and central Rocky Mountains have successfully used plots 5 m (16.4 ft) by 10 m (32.8 ft) on a side, total area of 50 m² (538 ft²), for sampling a broad range of riparian-wetland communities, including tall shrub types (Mattson 1984; Platts and others 1987; Tuhy and Jensen 1982; Youngblood and others 1985a, b). For long stringer communities the plot width was reduced and length increased to maintain a constant plot size of 50-m² (538-ft²). The 50-m² (538-ft²) plot size was considered adequate to include most species of a community, yet small enough for the sampler to see the entire plot. Typically each plot was located within a stand that was at least twice the area of the plot. This was done to avoid sampling ecotones between communities. Forest communities were sampled using a 375-m² (35.8-ft radius) circular plot. Again, in long stringer communities the plot size was adjusted accordingly.

Canopy cover (Daubenmire 1959) by species was ocularly estimated within each plot. Plants not identified in the field were collected for later identification in the office.

Physical site features were also collected for each plot and included: soil description, depth to water table, depth to a restrictive layer, mottling/gleying, amount of organic matter, and stream characteristics. Other data collected for each plot included elevation, slope, aspect, position, configuration, disturbance, successional relationships, and adjacent communities.

OFFICE METHODS

Development of the Montana riparian-wetland site classification followed six general procedures:

1. Specimens of plants were identified in the office or at the University of Montana herbaria.

2. Data were entered into FUZPHY, a computer data analysis system developed by Dave Roberts of Utah State University, capable of summarizing large quantities of vegetation and environmental data.

3. A stepwise procedure of "successive approximations" was used to develop the classification (Pfister and Arno 1980). Preliminary association tables were created using plot species and canopy cover values. Stands were then rearranged several times to group stands into sets with the greatest vegetation similarities. Plot-to-plot similarity relations, plot-to-set similarity relations, and set-to-set similarity relations were analyzed using a modified Sorensen's Index (the program SIMREL in FUZPHY). The final placement of each sample plot in a set was based on both floristic and environmental relationships.

4. Average canopy cover, canopy cover range, and constancy tables were created for each group.

5. A dichotomous key to the preliminary types was developed based on the presence or abundance of diagnostic plant species that indicate the presence of certain environmental conditions (indicator species). The key was then applied to all plots and necessary revisions were made to accommodate variations in the data.

6. A description was prepared for each habitat type (h.t.) and community type (c.t.). A general discussion of vegetation, physical environments, and management implications was included.

TAXONOMIC CONSIDERATIONS

Taxonomic nomenclature follows Brunsfeld and Johnson (1985) for the Salicaceae. All other taxa follow Barkley (1986) and Hitchcock and others (1969).

Occasionally, some species presented problems in positive identification. Due to the frequent absence of inflorescences and to similarities in morphology and ecological amplitude, Geyer willow (*Salix geyeriana*) includes Lemmon willow (*Salix lemmonii*) (Great Plains Flora Association 1986).

ECOLOGICAL TERMS AND CONCEPTS

Concepts and terminology are consistent with usage proposed by Daubenmire (1952, 1968, 1978) and used in numerous studies of vegetation-based ecological site classification (habitat types) (Alexander 1985; R. R. Alexander and others 1986; B. G. Alexander and others 1984a, b; Cooper 1975, 1981; Cooper and Pfister 1985; Cooper and others 1987; Daubenmire 1952, 1970; Daubenmire and Daubenmire 1968; DeVelice and others 1986; Hanks and others 1983; Hansen and Hoffman 1988; Hansen and others 1984; Hironaka and others 1983; Hoffman and Alexander 1976, 1980, 1983, 1987; Jorgensen 1979; Kovalchik 1987; Mauk and Henderson 1984; Moir and Ludwig 1979; Mueggler and Stewart 1980; Pfister and Arno 1980; Pfister and others 1977; Steele and Geier-Hayes 1987; Steele and others 1981; Tiedeman and others 1987; Youngblood and Mauk 1985). For a review of vegetation-based ecological site classifications (habitat types), see Ferguson and others (1989) and Pfister (1989).

Climax vegetation is that which has attained a steady state with its environment, and in the absence of excessive disturbance, species of climax vegetation successfully maintain their population sizes. *Seral vegetation* is that which has theoretically not attained a steady state, and current populations of some species are being replaced by other species. A *habitat type* (h.t.) is defined as the land area that supports, or has the potential of supporting, the same climax vegetation. Each habitat type represents a relatively narrow segment of environmental variation having a certain potential for vegetation development. Although any given habitat type may support a wide variety of disturbance-induced or seral vegetation, the ultimate product of vegetational succession anywhere within that habitat type will be a similar plant community. Therefore, the habitat type is a vegetation-based ecological site classification that uses the plant community as an indicator of integrated environmental factors as they affect species reproduction and plant community development. Habitat types have been used to classify grasslands, shrublands, woodlands, and forests throughout the Western United States. The habitat type classification system is currently being applied to lands in the Central and Eastern United States.

The concepts and many of the terms used within this classification were first proposed by Tansley (1935) and later modified by Daubenmire (1952). *Primary climaxes* develop on habitats where recurring disturbance is not a

factor influencing the structure or composition of the vegetation. *Climatic climax* vegetation develops on normal topography with fairly deep, well-drained, loamy soil. Where topography or soil exert sufficient influence to produce a self-perpetuating, steady-state vegetation distinct from the climatic climax, the terms *topographic climax* or *edaphic climax,* respectively, are used. Where special topographic conditions also favor the development of edaphic conditions distinct from the normal, and the climax vegetation is distinct from the climatic climax, the term *topoedaphic climax* is used. Where recurring disturbances, such as grazing or fire, exert the predominant influence in maintaining the structure and composition of the steady-state vegetation, the term *disclimax* is used. A *zootic climax* is stable vegetation that is distinct as a result of heavy use by animals. *Fire climax* is apparently stable vegetation that is distinctive as a result of periodic burning. *Disclimaxes, such as the zootic climax or fire climax, are not the basis for recognizing riparian habitat types*.

The term *plant association* is used to group together all those stands of climax vegetation that occur in environments so similar that there is much floristic similarity throughout all layers of the vegetation. For our work, we have chosen to follow the lead of Kovalchik (1987) in the development of a vegetation-based ecological site classification for riparian-wetland areas. Kovalchik (1987) uses the term *riparian association* as a vegetation type representing the latest successional stage attainable on a specific hydrologically influenced surface. Because the riparian association is the end result of plant succession, it reflects the most meaningful integration of environmental factors affecting vegetation. It is important to remember that the potential of a site may change if there is a dramatic change in the soil or water characteristics of the site. For example, this can occur due to the erosional and depositional effects of stream meandering. It may also change if the site is dewatered (for example, the water table has been lowered either by human-induced actions [wetland draining] or by heavy livestock impacts), or if the site is now permanently flooded due to either human-induced activity or beaver activity (beaver ponds). In any case, the site potential has changed, which in turn will result in a different climax vegetation type (association).

In addition, we have sampled and described several major seral plant communities that are stable for time frames relevant to land management decisions. A *community type* (c.t.) is an aggregation of all plant communities distinguished by floristic and structural similarities in both overstory and undergrowth layers. Examples are the Geyer willow/Kentucky bluegrass (*Salix geyeriana/Poa pratensis*) c.t. and the sandbar willow (*Salix exigua*) c.t. However, in this classification the term *community type* can only represent seral or disclimax communities because the climax community types are defined as riparian associations.

Our goal is to provide understanding of plant communities in relation to factors of time, physical environment (site), and treatment, and to document that understanding through a user-oriented taxonomic classification system. The concepts and terminology are illustrated in figure 1 for further clarification. The upper cell is the *riparian plant association* (climax vegetation type). After riparian associations are identified and defined, a taxonomic key is written to define the column (physical environment = site) that represents the *habitat type*. This key allows identification of the habitat type in most stages of succession. In some instances, the successional relationships are known. For example, community types A-2, A-3, and A-4 represent specific and clearly identified
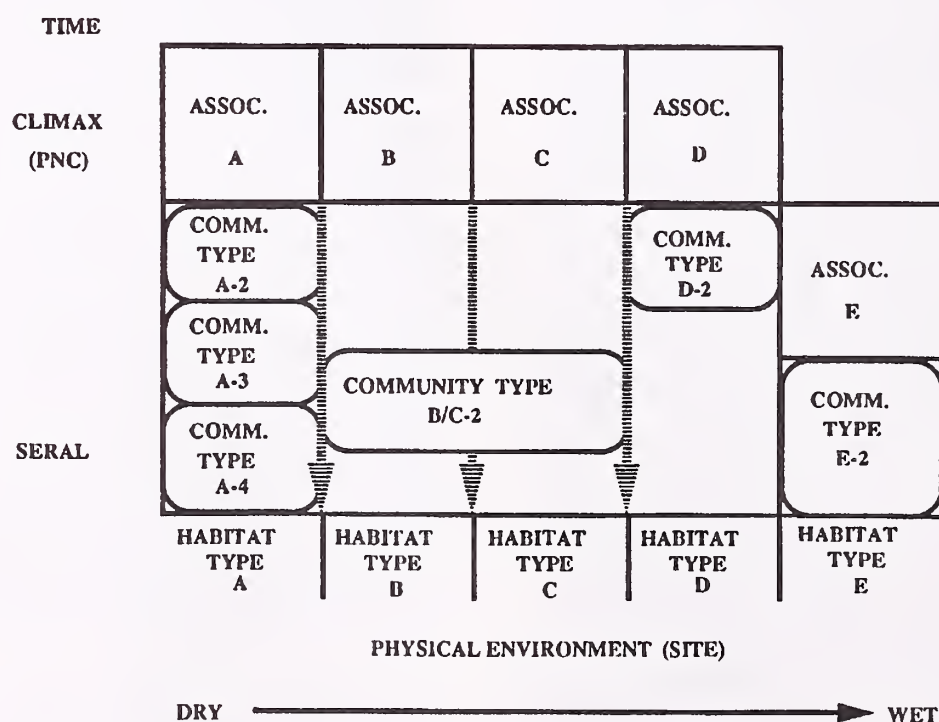

Figure 1—Illustration of the terminology as it relates to time and space (physical environment = site) for riparian-wetland sites.

successional stages within riparian association A. On the other hand, community type B/C-2 represents a grazing disclimax that extends over two or more habitat types with insufficient evidence to distinguish the specific type (column). In riparian association D, our present knowledge base only allows us to identify one seral stage, such as community type D-2. Finally, riparian association E represents the situation in which the time frame for the successional pathway is brief and the climax vegetation type (riparian association) is obtained after just a few years. In general, this pathway occurs when the pioneering species is a very aggressive plant that also represents the climax vegetation for the site, such as in the case of beaked sedge (*Carex rostrata*) and common cattail (*Typha latifolia*).

Naming of the association follows the frequently used system of a binomial set with the dominant overstory species separated by a slash from the dominant or most diagnostic indicator of the undergrowth union. For example, numerous stands of the Geyer willow/beaked sedge (*Salix geyeriana/Carex rostrata*) riparian association occur. The units of land on which these occur represent the Geyer willow/beaked sedge h.t. This latter nomenclature is useful because throughout the study region most parcels of land support vegetation in a successional stage (seral stage). Where those land units are recognized to be part of the Geyer willow/beaked sedge h.t., they are so categorized. Thus a multitude of variation in the matrix of vegetation over the landscape theoretically can be categorized into a manageable number of units. The categories are defined to represent as close as possible the natural biotic potential (climaxes) of the region. A *phase* is a subdivision of a habitat type representing a minor variation in climax vegetation and environmental conditions. An example is the beaked sedge h.t., beaked sedge phase. However, some riparian-wetland communities consist of only a single layer of vegetation; we consider this the overstory and ignore all references to additional layers (for example, the mud sedge [*Carex limosa*] h.t.).

The habitat type classification provides a permanent and ecologically based system of land stratification in terms of vegetational potential (Daubenmire 1976). As the habitat type is the basic unit in classifying land units or sites based on their biotic potential, it emphasizes similarities and differences in ecosystems that carry implications for a variety of land management objectives (Daubenmire 1984). Some of the practical implications of habitat type classification are in predicting range and wildlife forage production and wildlife habitat values, inventory, landtype mapping, timber production, species selection for regeneration or rehabilitation methods, development of best management practices, growth rates of trees and shrubs, susceptibility of trees and shrubs to insects and disease, depth of soil moisture penetration, potential for producing browse after fire, soil management criteria, impacts of recreational uses, natural areas for preservation, downed woody fuels on the forest floor, and successional trends following disturbance. In addition, habitat types offer a basis of comparison and evaluation in designing and carrying out field experiments in ecology or applied natural resource disciplines.

SUCCESSION

Two types of succession affect vegetation development: (1) *primary succession*, and (2) *secondary succession*. Succession that creates new soil surfaces, such as filling in a lake or development of vegetation on an alluvial bar, is considered *primary succession*. This is a slow process that may require many centuries to reach a stable or climax community. Secondary succession occurs after a disturbance alters or destroys the vegetation cover, but does not destroy the soil, such as a fire that removes forest or shrubland vegetation. Regeneration (*secondary succession*) usually happens quickly, unless subsequent erosion removes the soil down to bedrock. However, a fire in a fen may burn enough peat to create a pond during wet seasons and initiate primary succession.

Generally speaking, ecologists and land managers have only had to deal with secondary succession when working with nonwetland or upland sites. However, in many riparian-wetland situations, primary succession is just as important as secondary succession in expressing the overall landscape mosaics.

The timeframe for successional processes varies greatly, depending upon the type, location, and origin of the riparian-wetland area. For example, some beaver ponds silt in within a few dozen years while others may take hundreds of years to silt. The analysis of a few mountain meadows has shown that they have been stable for the last 6,900 years (Windell and others 1986). In the Madison Range, MT, Patten (1963) considered that the vegetation was still adjusting to the post-Pleistocene climate, but that vegetation patterns, including mountain meadows, are relatively stable.

As it is theoretically the end result of succession, the climax plant community (plant association) is an expression of the biotic potential of the site where it occurs. Each habitat type is a relatively narrow segment of environmental variation and is defined by a certain potential for vegetational development. Although one habitat type may support a variety of disturbance-induced, or seral, plant communities, the potential product of vegetational succession anywhere within one habitat type will be a similar climax community. Therefore, the habitat type classification uses the plant community as an indicator of environmental factors as they affect species reproduction and plant community development.

If succession can be recognized and understood, the long-term product of succession is the climax, or steady-state, community. In so far as this community is self perpetuating and its distinctiveness is time independent, it represents a meaningful integration of its total environment. It is on this basis that the climax vegetation is useful in the nomenclature of habitat types.

The following riparian-wetland shrub habitat types and community types were identified for Montana (Hansen and others 1991). The willow habitat types include the Drummond willow/beaked sedge (*Salix drummondiana/ Carex rostrata*) h.t., Drummond willow/bluejoint reedgrass (*Salix drummondiana/Calamagrostis canadensis*) h.t., Geyer willow/beaked sedge (*Salix geyeriana/Carex rostrata*) h.t., Geyer willow/bluejoint reedgrass (*Salix*

geyeriana/Calamagrostis canadensis) h.t., hoary willow/ beaked sedge (Salix candida/Carex rostrata) h.t., plane-leaf willow/water sedge (Salix planifolia/Carex aquatilis) h.t., Wolf's willow/tufted hairgrass (Salix wolfii/ Deschampsia cespitosa) h.t., Wolf's willow/water sedge (Salix wolfii/Carex aquatilis) h.t., yellow willow/beaked sedge (Salix lutea/Carex rostrata) h.t., and yellow willow/ bluejoint reedgrass (Salix lutea/Calamagrostis canadensis) h.t. The willow community types include the Bebb willow (Salix bebbiana) c.t., Drummond willow (Salix drummondiana) c.t., Geyer willow (Salix geyeriana) c.t., Pacific willow (Salix lasiandra) c.t., sandbar willow (Salix exigua) c.t., and yellow willow (Salix lutea) c.t.

SERAL STAGES

Personal observations by the authors tend to indicate that Geyer willow is a preferentially browsed species over Booth willow. This may account for the reduced abundance and canopy cover of Geyer willow in select stands of the Geyer willow/beaked sedge h.t.

Heavy cutting of the willows by beaver may lead to dominance by the graminoids. If beaver leave the area because of the lack of food, or are removed by trapping, major storm events or seasonal runoff can cause the dams to be washed out. With the elimination of beaver, the dams will not be repaired, resulting in downcutting and, eventually, a lowering of the water table. The lowering of the water table can result in the changing of the site's potential. If the water table equilibrates at a new but lower (drier) state, the site's potential changes to the Geyer willow/bluejoint reedgrass h.t. The Geyer willow/ bluejoint reedgrass h.t. occupies a slightly drier position on the landscape than that of the Geyer willow/beaked sedge h.t.

SOILS

Soils have generally developed through the accumulation of fine materials on ponded or previously ponded sites. Soils are typically fine-textured Aquolls and Borolls or, rarely, Inceptisols and Entisols (Brichta 1987). Water tables remain near the surface throughout the summer, and gleying is evident at depths of 20-35 cm (7.9-13.8 inches). Estimated available water-holding capacity ranged from moderate to high. Soil reactions are neutral to mildly alkaline.

The nonwillow habitat types include the black greasewood/western wheatgrass (Sarcobatus vermiculatus/ Agropyron smithii) h.t., bog birch/beaked sedge (Betula glandulosa/Carex rostrata) h.t., shrubby cinquefoil/tufted hairgrass (Potentilla fruticosa/Deschampsia cespitosa) h.t., silver sagebrush/western wheatgrass (Artemisia cana/Agropyron smithii) h.t., silver sagebrush/Idaho fescue (Artemisia cana/Festuca idahoensis) h.t., and small-leaved laurel/Holm's Rocky Mountain sedge (Kalmia microphylla/Carex scopulorum) h.t. The nonwillow community types include the common chokecherry (Prunus virginiana) c.t., Douglas's spiraea (Spiraea douglasii) c.t., mountain alder (Alnus incana) c.t., red-osier dogwood (Cornus stolonifera) c.t., sitka alder (Alnus sinuata) c.t., succulent hawthorn (Crataegus succulenta) c.t., thorny

buffaloberry (Shepherdia argentea) c.t., water birch (Betula occidentalis) c.t., western snowberry (Symphoricarpos occidentalis) c.t., and woods rose (Rosa woodsii) c.t.

The following represents a typical discussion of both a riparian-wetland shrub habitat type and community type as described by Hansen and others (1991) in the publication "Classification and Management of Riparian and Wetland Sites In Montana."

Geyer Willow/Beaked Sedge Habitat Type

SALGEY/CARROS (SAGE2/CARO6)
Number of stands sampled = 53.

LOCATION AND ASSOCIATED LANDFORMS
The Geyer willow/beaked sedge h.t. is a major type at mid- to moderately high elevations throughout the mountains and valleys of Montana. It occurs on wet streambanks, terraces, seeps and springs, and on ponded areas near abandoned beaver ponds. On larger streams with well-developed floodplains, this type may occur as part of a diverse mosaic of sites due to varying degrees of wetness and the influence of flooding, scouring, and channel changes. The Geyer willow-Booth willow (Salix boothii)-dominated types occupy intermediate elevations in comparison to the yellow willow-dominated types, which occupy lower foothills, and the Drummond willow-dominated types, which occupy the higher elevation sites. Sites for the Geyer willow/beaked sedge h.t. range in elevation from 1,463-2,143 m (4,800-7,030 ft).

FLORISTIC CHARACTERISTICS OF SAMPLED STANDS
Geyer willow and Booth willow are the most common shrubs. The undergrowth is dominated by beaked sedge with lesser amounts of water sedge (Carex aquatilis) also present. Large-leaved avens (Geum macrophyllum) is the most common forb associated with this type.

Table 1 gives the average canopy cover (in stands in which the species occurred) and range of indicator species or those species with a 50 percent or more constancy (occurs in at least 50 percent of the stands sampled).

Table 1—Canopy cover and indicator species for the Geyer willow/ beaked sedge habitat type

| Species | Percent canopy cover | | |
	Average	Range	Constancy
Shrubs			
Booth willow	28	0-15	57
Geyer willow	33	5-35	85
Graminoids			
awned sedge (Carex atherodes)	20	0-45	4
beaked sedge	47	0-45	89
inflated sedge (Carex vesicaria)	18	0-15	9
water sedge	20	0-25	49
Forbs			
common willow-herb (Epilobium ciliatum)	1	0-5	31
large-leaved avens	2	0-25	65
western aster (Aster occidentalis)	4	0-55	35

ADJACENT COMMUNITIES

Adjacent sites that are slightly wetter support the beaked sedge h.t., the common cattail (*Typha latifolia*) h.t., or open water. The Geyer willow/bluejoint reedgrass h.t. or the Geyer willow c.t. may occupy adjacent drier sites. Other communities on drier disturbed sites include the Kentucky bluegrass (*Poa pratensis*), redtop (*Agrostis stolonifera*), and Baltic rush (*Juncus balticus*) community types and the shrubby cinquefoil/tufted hairgrass h.t. Uplands are dominated by conifers such as Douglas-fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*), and ponderosa pine (*Pinus ponderosa*), or by shrubs and grasses such as big sagebrush (*Artemisia tridentata*) and Idaho fescue (*Festuca idahoensis*).

MANAGEMENT INFORMATION

Livestock

Forage value of beaked sedge and water sedge is variable, depending on season, previous grazing use, and the extent of the site. On narrow riparian or wetland sites within extensive rangelands, sedge species are heavily utilized, particularly when upland species are cured, or stock distribution is poor.

Overuse by livestock will result in a reduced vigor by the willows present, as illustrated by uneven stem age distribution, highlining, clubbing, or dead clumps. With continued overuse, willows show a sharp decline in vigor and may be eventually eliminated from the site.

Deferred and rest-rotation grazing systems generally favor sedge species over willow species since woody species are vulnerable to longer duration treatments and to late summer-fall treatments (Myers 1989). Woody species are vulnerable to pruning damage, while sedges are protected by a root reserve. Late summer and fall grazing should be carefully controlled with duration of treatments limited to less than 30 days and frequency of this treatment to about one year in three or four (Myers 1989).

Personal observations by the authors tend to indicate that Geyer willow is a preferentially browsed species by livestock over Booth willow. This may account for the reduced abundance and canopy cover of Geyer willow in select stands of the Geyer willow-dominated types.

Wildlife

A diversity of wildlife species, ranging from large mammals to rodents and songbirds, use this type for food, cover, and nesting. Moose and beaver tend to heavily utilize most species of willows.

Research by McMillan (1953), Gaffney (1941), and Chadde and Kay (1988) and personal observations by the authors tend to indicate that Geyer willow is a preferred browse species by ungulates over Booth willow. This may account for the reduced canopy cover and occurrence of Geyer willow in select stands of the Geyer willow-dominated types.

Fisheries

The dense network of roots from the various willows and the rhizomatous beaked sedge and water sedge are effective in stabilizing streambanks. Immediately adjacent to the stream, the sedge sod may be undercut and sag into the water, providing excellent cover for fish. In addition, the various species of willows provide valuable overhanging stream cover and shade. The importance of willows in streambank protection, cover, and thermal protection for fisheries cannot be emphasized enough. In addition, the herbaceous understory aids in filtering out sediments during high flows, thereby contributing to the overall building of the streambanks. Some stands may be so dense as to hinder most forms of recreational fishing. If fishing access is important, dense stands may be opened by the use of livestock as a management tool.

Fire

Prescribed burning in the Geyer willow/beaked sedge h.t. is an effective method of rejuvenating decadent clumps. The various willow species present in this type sprout vigorously following fire, especially in wetter stands (Kovalchik 1986, 1987). Quick, hot fires result in more sprouts than slower fires, which are potentially more damaging to the willows and tend to result in fewer sprouts.

Burning of this type can temporarily increase productivity of beaked sedge, water sedge, and inflated sedge. However, nonuse by livestock during the year prior to burning is essential. Residual cover burns well in the spring, prior to the growing season. Care should be taken when burning stands along streambanks because of the excellent erosion protection provided by the Geyer willow/ beaked sedge h.t.

Soil Management and Rehabilitation Opportunities

The wet nature of the soil makes it highly susceptible to trampling and compaction by livestock and heavy machinery. Soil surfaces may be churned by livestock if used when moist, resulting in soil compaction, streambank sloughing, and damage to vegetation. Management should emphasize the importance of willows in protecting the streambank. Woody species provide the greatest amount of streambank protection, not the herbaceous species.

Geyer willow is valuable in revegetating disturbed streambanks. Cuttings should be first rooted then grown in a nursery to ensure survival. Cuttings, however, may be more difficult to root than Booth willow. Cut stems of Geyer willow produce low to moderate numbers of roots, located along the entire length of the stem. Best results are obtained from cuttings taken in the spring from dormant 2- to 4-year-old wood. Cuttings 30-50 cm (11.8-19.7 inches) long and >1 cm (0.4 inch) in diameter produce the best results. Roots and shoots from cuttings can be expected to appear 10-15 days after planting.

Beaked sedge, water sedge, and inflated sedge all tend to form a dense, thick sod that is highly resistant to erosion. Along the stream, the sod may be undercut and sag into the water, providing additional protection to streambanks. However, if grazing or trailing impacts are severe, the heavy weight of the sod makes it susceptible to damage, and streambank sloughing can occur.

Recreational Uses and Considerations

This habitat type is commonly adjacent to fisheries, and streamside trails may develop. Some stands may be so dense as to hinder most forms of recreational fishing. If fishing access is important, dense stands may be opened by the use of livestock as a management tool.

OTHER CLASSIFICATION SYSTEMS

Two additional classification systems that are being used to describe/define riparian and wetland ecosystems are given here along with the appropriate "type(s)" that best describes this particular habitat type or community type. In general, both systems define broad categories containing many dissimilar habitat types (vegetation-based ecological site classification system). For example, one range site may contain more than 10 very different habitat types. In other instances, no comparable "type(s)" could be determined.

USDI Fish and Wildlife Service Wetland Classification (Cowardin and others 1979). SYSTEM Palustrine, CLASS Scrub-Shrub, SUBCLASS Broad-leaved Deciduous, WATER REGIME (NONTIDAL) Seasonally Flooded to Saturated.

USDA Soil Conservation Service Range Site Classification (USDA Soil Conservation Service 1983): (1) foothills and mountains; 25.4-35.6 cm (10-14 inches) precipitation zone = subirrigated range site and wet meadow range site, (2) foothills and mountains; 38.1-48.3 cm (15-19 inches) precipitation zone = subirrigated range site and wet meadow range site, (3) foothills and mountains; 50.8 cm (20 inches) plus precipitation zone = subirrigated range site and wet meadow range site, (4) Northern Rocky Mountain valley bottoms, west of the Continental Divide; 25.4-35.6 cm (10-14 inches) precipitation zone = subirrigated range site and wet meadow range site, (5) Northern Rocky Mountain valleys, west of the Continental Divide; 38.1-48.3 cm (15-19 inches) precipitation zone = subirrigated range site and wet meadow range site, and (6) Northern Rocky Mountain parks, west of the Continental Divide; 50.8 cm (20 inches) plus precipitation zone = subirrigated range site and wet meadow range site.

OTHER STUDIES

Similar communities, codominated by Geyer willow and Booth willow, have been described by a number of researchers: Norton (1981, Greys River, WY); Mutz and Queiroz (1983, southeastern Idaho); Youngblood and others (1985, eastern Idaho and western Wyoming); Chadde and others (1988, Yellowstone National Park); Padgett and others (1989, Utah).

Sandbar Willow Community Type

SALEXI (SAEX)

Number of stands sampled = 92.

LOCATION AND ASSOCIATED LANDFORMS

The sandbar willow c.t. is a major, widespread type at low- to mid-elevations throughout Montana. Sites range from 777 to 1,754 m (2,550 to 5,750 ft). Typical sites occupied by this type are sand and cobble deposits subject to periodic flooding each year, ditches, and lakeshores.

FLORISTIC CHARACTERISTICS OF SAMPLED STANDS

Major shrub species of this community type are sandbar willow, with some stands having large amounts of woods rose (*Rosa woodsii*), prickly rose (*Rosa acicularis*), and red-osier dogwood (*Cornus stolonifera*). Other species of willow may be present, indicating a possible successional trend toward willow communities dominated by yellow willow, Geyer willow, and Booth willow. Grasses present include redtop and Kentucky bluegrass. The most common forb is Canada thistle (*Cirsium arvense*).

Table 2 gives the average percent canopy cover (in stands in which the species occurred) and range of indicator species or those species with a 50 percent or more constancy (occurs in at least 50 percent of the stands sampled).

POTENTIAL NATURAL COMMUNITY

The sandbar willow c.t. is a seral stage that may persist under a regime of repeated fluvial disturbance. Sandbar willow is a pioneer or early seral species on newly deposited, coarse alluvial materials. It commonly occurs in open black cottonwood (*Populus trichocarpa*), narrowleaf cottonwood (*Populus angustifolia*), or Great Plains cottonwood (*Populus deltoides*) stands, or as a fringe around dense cottonwood stands.

In the eastern portion of Montana, many stands are seral to either the green ash/common chokecherry (*Fraxinus pennsylvanica*/*Prunus virginiana*) h.t. or the boxelder/common chokecherry (*Acer negundo*/*Prunus virginiana*) h.t. Seedlings of both sandbar willow and Great Plains cottonwood are typically established at the same time on alluvial mud flats. Initially, sandbar willow may grow faster than Great Plains cottonwood. However, in a few short years, saplings of Great Plains cottonwood will overtop sandbar willow and begin to dominate the overstory canopy. As the dense overstory canopy of Great Plains cottonwood matures, sandbar willow is shaded out. At the same time that sandbar willow is being shaded out, the understory is beginning to be dominated by seedlings, saplings, and pole-size green ash.

In the mountains and lower foothills of eastern and central Montana, the sandbar willow c.t. may represent a successional stage of the Geyer willow/bluejoint reedgrass h.t. or the yellow willow/ bluejoint reedgrass h.t., depending on elevation. Heavy grazing pressures may cause some sites to go to the Geyer willow c.t. or the yellow willow c.t.

DISTURBANCE STAGES

Sandbar willow is highly adapted to most forms of disturbance. It is a prolific sprouter and will reestablish

Table 2—Canopy cover and indicator species for the sandbar willow community type

Species	Percent canopy cover		
	Average	Range	Constancy
Shrubs			
sandbar willow	67	25-100	100
woods rose	22	0-75	48
Graminoids			
Kentucky bluegrass	32	0-75	24
redtop	21	0-95	42
smooth brome (*Bromus inermis*)	38	0-95	24
Forbs			
Canada thistle	16	0-75	46

itself following release from heavy grazing pressure, provided it has not been totally removed from the site. In addition, heavy grazing may open up stands, resulting in invasion by introduced species or nonpalatable native species.

SOILS

Soils of the sandbar willow c.t. are Entisols (Fluvents), or rarely Mollisols, and consist of thin sandy loams overlying sand deposits, gravels, or cobbles (Brichta 1987). Soils are usually moist in the spring and early summer and may remain saturated throughout the growing season. The coarse-textured soils, moderate stream gradients, and large amounts of coarse rock fragments in the soil profile provide for an environment in which the rapid movement of highly aerated water can occur. This type of substrate is important to many floodplain communities.

ADJACENT COMMUNITIES

Wetter communities are usually absent. Adjacent drier communities include the black cottonwood, narrowleaf cottonwood, Great Plains cottonwood, Geyer willow, and Kentucky bluegrass types. Upland communities are dominated by conifers and shrubs and grasses such as big sagebrush, silver sagebrush (*Artemisia cana*), black greasewood (*Sarcobatus vermiculatus*), western wheatgrass (*Agropyron smithii*), and Idaho fescue.

MANAGEMENT INFORMATION

Livestock

Forage production is low to occasionally moderate because of the high densities of sandbar willow stems. Dense stands limit livestock access.

Overuse by livestock will result in a reduced vigor by the willows present, as illustrated by uneven stem age distribution, highlining, clubbing, or dead clumps. With continued overuse, willows show a sharp decline in vigor and may be eventually eliminated from the site. However, release from heavy grazing pressure will allow it to reestablish itself, provided it has not been totally removed from the site.

Wildlife

Stands of this community type provide excellent thermal and hiding cover for many species of wildlife. Sandbar willow is normally not as heavily browsed as other more palatable willow species. Beaver tend to heavily utilize sandbar willow.

Fisheries

The sandbar willow c.t. typically provides only a limited amount of overhanging shade due to the upright growth form of this species. The importance of willows in streambank protection for fisheries cannot be emphasized enough. In addition, the herbaceous understory aids in filtering out sediments during high flows, thereby contributing to the overall building of the streambanks. Some stands may be so dense as to hinder most forms of recreational fishing. If fishing access is important, dense stands may be opened by the use of livestock as a management tool.

Fire

The use of fire in this type as an improvement technique has been little studied. However, limited information indicates this type tends to sprout vigorously following fire. Quick, hot fires result in more sprouts than slower fires, which are potentially more damaging to the willows and tend to result in fewer sprouts.

Soil Management and Rehabilitation Opportunities

Soil compaction is usually not a problem on coarse-textured soils and substrates. Fine-textured deposits may be subject to compaction when moist. Unlike most other willows, sandbar willow can send up individual stems from a complex underground root system, making it an excellent woody species for stabilizing streambanks. Management should emphasize the importance of willows in protecting the streambank. Woody species provide the greatest amount of streambank protection, not the herbaceous species.

Sandbar willow is a pioneering species commonly found along irrigation ditches, cutbanks, and wet areas adjacent to roads. It has an excellent capability to rapidly colonize and spread on disturbed areas, making it useful in streambank stabilization and revegetation projects at low to mid-elevations. Once sandbar willow has stabilized soils, other shrub and herbaceous species may become established. Because of this characteristic, it would be wise for farmers, ranchers, and other land managers to maintain these stands. Once degradation occurs, rapid erosion of the streambank can occur with devastating results.

Sandbar willow is highly adapted to most forms of disturbance. It is a prolific sprouter and will reestablish itself following release from heavy grazing pressure, provided it has not been totally removed from the site.

Revegetating degraded sites or exposed sand/gravel bars is feasible using sandbar willow. Cuttings should be first rooted then grown in a nursery to ensure survival. Sandbar willow produces an abundance of roots along the entire stem. Cuttings are best taken in the spring from dormant 2- to 4-year-old wood. Cuttings 30-50 cm (11.8-19.7 inches) long and >1 cm (0.4 inch) in diameter produce the best results. Roots and shoots from cuttings can be expected to appear 10 days after planting.

Recreational Uses and Considerations

Recreational opportunities are limited because of dense thickets and large mosquito populations.

OTHER CLASSIFICATION SYSTEMS

Two additional classification systems that are being used to describe/define riparian and wetland ecosystems are given here along with the appropriate "type(s)" that best describes this particular habitat type or community type. In general, both systems define broad categories containing many dissimilar habitat types (vegetation-based ecological site classification system). For example, one range site may contain more than 10 very different habitat types. In other instances, no comparable "type(s)" could be determined.

USDI Fish And Wildlife Service Wetland Classification (Cowardin and others 1979). SYSTEM Palustrine, CLASS Scrub-Shrub, SUBCLASS Broad-leaved Deciduous, WATER REGIME (NONTIDAL) Saturated to Temporarily Flooded.

USDA Soil Conservation Service Range Site Classification (USDA Soil Conservation Service 1983): (1) eastern glaciated plains; 25.4-35.6 cm (10-14 inches) precipitation zone = subirrigated range site and wet meadow range site, (2) western glaciated plains; 25.4-35.6 cm (10-14 inches) precipitation zone = subirrigated range site and wet meadow range site, (3) eastern sedimentary plains; 25.4-35.6 cm (10-14 inches) precipitation zone = subirrigated range site and wet meadow range site, (4) eastern sedimentary plains; 38.1-48.3 cm (15-19 inches) precipitation zone = subirrigated range site and wet meadow range site, (5) western sedimentary plains; 25.4-35.6 cm (10-14 inches) precipitation zone = subirrigated range site and wet meadow range site, (6) foothills and mountains; 25.4-35.6 cm (10-14 inches) precipitation zone = subirrigated range site and wet meadow range site, (7) foothills and mountains; 38.1-48.3 cm (15-19 inches) precipitation zone = subirrigated range site and wet meadow range site, (8) foothills and mountains; 50.8 cm (20 inches) plus precipitation zone = subirrigated range site and wet meadow range site, (9) Northern Rocky Mountain valley bottoms, west of the Continental Divide; 25.4-35.6 cm (10-14 inches) precipitation zone = subirrigated range site and wet meadow range site, (10) Northern Rocky Mountain valleys, west of the Continental Divide; 38.1-48.3 cm (15-19 inches) precipitation zone = subirrigated range site and wet meadow range site, and (11) Northern Rocky Mountain parks, west of the Continental Divide; 50.8 cm (20 inches) plus precipitation zone = subirrigated range site and wet meadow range site.

OTHER STUDIES

Similar sandbar willow community types have been described by Norton and others (1981, Greys River, WY), Mutz and Queiroz (1983, southeastern Idaho), Tuhy and Jensen (1982, central Idaho), Youngblood and others (1985b, eastern Idaho and western Wyoming), Padgett and others (1989, Utah and southeastern Idaho), Chadde and others (1988, northern Yellowstone National Park), and Szaro (1989, Arizona and New Mexico). Undergrowth composition varied widely but was often composed of introduced grasses such as redtop, fowl bluegrass (*Poa palustris*), and Kentucky bluegrass.

REFERENCES

Alexander, Billy G., Jr.; Ronco, Frank, Jr.; Fitzhugh, E. Lee; Ludwig, John A. 1984a. A classification of forest habitat types of the Lincoln National Forest, New Mexico. Gen. Tech. Rep. RM-104. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 29 p.

Alexander, Billy G., Jr.; Ronco, Frank, Jr.; White, Alan S.; Ludwig, John A. 1984b. Douglas-fir habitat types of northern Arizona. Gen. Tech. Rep. RM-108. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 13 p.

Alexander, Robert R. 1985. Major habitat types, community types, and plant communities in the Rocky Mountains. Gen. Tech. Rep. RM-123. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 105 p.

Alexander, Robert R.; Hoffman, George R.; Wirsing, John M. 1986. Forest vegetation of the Medicine Bow National Forest in southeastern Wyoming: a habitat type classification. Res. Pap. RM-271. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 39 p.

Barkley, T. M., ed. 1986. Flora of the Great Plains. Great Plains Flora Association. Lawrence, KS: University Press of Kansas. 1392 p.

Brichta, Paul H. 1987. Environmental relationships among wetland community types of the northern range, Yellowstone National Park. Missoula, MT: University of Montana. 74 p. Thesis.

Brunsfeld, Steven J.; Johnson, Frederic D. 1985. Field guide to the willows of east-central Idaho. Moscow, ID: University of Idaho. Forest, Wildlife and Range Experiment Station. 95 p.

Chadde, Steve; Kay, Charles. 1988. Willows and moose: a study of grazing pressure, Slough Creek exclosure, Montana, 1961-1986. Res. Note 24. Missoula, MT: University of Montana, Montana Forest and Conservation Experiment Station, School of Forestry. 5 p.

Chadde, Steve W.; Hansen, Paul L.; Pfister, Robert D. 1988. Wetland plant communities of the northern range, Yellowstone National Park. Final Report. Missoula, MT: University of Montana, Montana Riparian Association, School of Forestry. 81 p.

Cooper, Stephen V. 1975. Forest habitat types of northwestern Wyoming and contiguous portions of Montana and Idaho. Pullman, WA: Washington State University. 190 p. Dissertation.

Cooper, Stephen V. 1981. Forest habitat types of the Blackfeet Indian Reservation. Final Report. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 87 p.

Cooper, Stephen V.; Neiman, Kenneth E.; Steele, Robert; Roberts, David W. 1987. Forest habitat types of northern Idaho: a second approximation. Gen. Tech. Rep. INT-236. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 135 p.

Cooper, Stephen V.; Pfister, Robert D. 1985. Forest habitat types of the Crow and Northern Cheyenne Indian Reservations. Final Report. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 103 p.

Cowardin, Lewis M.; Carter, Virginia; Golet, Francis C.; LaRoe, Edward T. 1979. Classification of wetlands and deepwater habitats of the United States. FWS/OBS-79/31. Washington, DC: U.S. Department of the Interior, Office of Biological Services, Fish and Wildlife Service. 103 p.

Daubenmire, R. D. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. Ecological Monographs. 22: 301-330.

Daubenmire, R. D. 1959. A canopy-coverage method of vegetation analysis. Northwest Science. 33: 43-66.

Daubenmire, R. D. 1968. Plant communities. New York: Harper and Row. 300 p.

Daubenmire, R. 1970. Steppe vegetation of Washington. Tech. Bull. 62. Pullman, WA: Washington State University, Washington Agricultural Experiment Station. 131 p.

Daubenmire, R. D. 1976. The use of vegetation in assessing the productivity of forest lands. Botanical Review. 42(2): 115-143.

Daubenmire, R. D. 1978. Plant geography with special reference to North America. New York: Academic Press. 338 p.

Daubenmire, R. D. 1984. Viewpoint: ecological site/range site/habitat type. Rangelands. 6: 263-264.

Daubenmire, R.; Daubenmire, J. B. 1968. Forest vegetation of eastern Washington and northern Idaho. Tech. Bull. 60. Pullman, WA: Washington State University, Washington Agricultural Experiment Station. 104 p.

DeVelice, Robert L.; Ludwig, John A.; Moir, William H.; Ronco, Frank, Jr. 1986. A classification of forest habitat types in northern New Mexico and southern Colorado. Gen. Tech. Rep. RM-131. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 59 p.

Ferguson, Dennis E.; Morgan, Penelope; Johnson, Frederic D., compilers. 1989. Proceedings—land classifications based on vegetation: applications for resource management; 1987 November 17-19; Moscow, ID. Gen. Tech. Rep. INT-257. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 315 p.

Gaffney, W. S. 1941. The effects of winter elk browsing, South Fork of the Flathead River, Montana. Journal of Wildlife Management. 5(4): 427-453.

Great Plains Flora Association. 1986. Flora of the Great Plains. Lawrence, KS: University Press of Kansas. 1392 p.

Hanks, Jess P.; Fitzhugh, E. Lee; Hanks, Sharon R. 1983. A habitat type classification system for ponderosa pine forests of northern Arizona. Gen. Tech. Rep. RM-97. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 22 p.

Hansen, Paul; Boggs, Keith; Pfister, Robert; Joy, John. 1991. Classification and management of riparian and wetland sites in Montana. Draft Version 1. Missoula, MT: University of Montana, Montana Riparian Association, Montana Forest and Conservation Experiment Station, School of Forestry. 478 p.

Hansen, Paul L.; Hoffman, George R. 1988. The vegetation of the Grand River/Cedar River, Sioux, and Ashland Districts of the Custer National Forest: a habitat type classification. Gen. Tech. Rep. RM-147. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 68 p.

Hansen, Paul L.; Hoffman, George R.; Bjugstad, Ardell J. 1984. The vegetation of Theodore Roosevelt National Park, North Dakota: a habitat type classification. Gen. Tech. Rep. RM-113. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 35 p.

Hironaka, M.; Fosberg, M. A.; Winward, A. H. 1983. Sagebrush-grass habitat types of southern Idaho. Bull. 35. Moscow, ID: University of Idaho, Forest, Wildlife, and Range Experiment Station, College of Forestry, Wildlife, and Range Sciences. 44 p.

Hitchcock, C. L.; Cronquist, A.; Ownbey, M.; Thompson, J. W. 1969. Vascular plants of the Pacific Northwest. Volumes 1-5. Seattle, WA: University of Washington Press.

Hoffman, George R.; Alexander, Robert R. 1976. Forest vegetation of the Bighorn Mountains, Wyoming: a habitat type classification. Res. Pap. RM-170. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 38 p.

Hoffman, George R.; Alexander, Robert R. 1980. Forest vegetation of the Routt National Forest, Colorado: a habitat type classification. Res. Pap. RM-221. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 41 p.

Hoffman, George R.; Alexander, Robert R. 1983. Forest vegetation of the White River National Forest, Colorado: a habitat type classification. Res. Pap. RM-249. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 36 p.

Hoffman, George R.; Alexander, Robert R. 1987. Forest vegetation of the Black Hills National Forest in western South Dakota and eastern Wyoming: a habitat type classification. Res. Pap. RM-270. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 48 p.

Jorgensen, Henry E. 1979. Vegetation of the Yellow Water Triangle, Montana. Montana Department of Fish and Game/USDI Bureau of Land Management. Unnumbered report. 57 p.

Kovalchik, Bernard L. 1986. Preliminary riparian community type classification of central Oregon. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 304 p. Unpublished draft.

Kovalchik, Bernard L. 1987. Riparian zone associations: Deschutes, Ochoco, Fremont, and Winema National Forests. Region 6 Ecol. Tech. Pap. 279-87. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 171 p.

Mattson, David J. 1984. Classification and environmental relationships of wetland vegetation in central Yellowstone National Park, WY. Moscow, ID: University of Idaho. 326 p. Thesis.

Mauk, R. L.; Henderson, J. A. 1984. Coniferous forest habitat types of northern Utah. Gen. Tech. Rep. INT-170. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 89 p.

McMillan, J. F. 1953. Some feeding habits of moose in Yellowstone Park. Ecology. 34: 102-110.

Moir, William, H.; Ludwig, John A. 1979. A classification of spruce-fir and mixed conifer habitat types of Arizona and New Mexico. Res. Pap. RM-207. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 47 p.

Mueggler, Walter F.; Stewart, W. L. 1980. Grassland and shrubland habitat types of western Montana. Gen. Tech. Rep. INT-66. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 154 p.

Mueller-Dombois, D.; Ellenberg, H. 1974. Aims and methods of vegetation ecology. New York: John Wiley and Sons. 547 p.

Mutz, K. M.; Queiroz, J. 1983. Riparian community classification for the Centennial Mountains and South Fork Salmon River, Idaho. Layton, UT: Meiiji Resource Consultants. 170 p. Unpublished report.

Myers, Lewis H. 1989. Grazing and riparian management in southwestern Montana. In: Gresswell, Robert E.; Barton, Bruce A.; Kershner, Jeffery L., eds. Practical approaches to riparian resource management: an educational workshop; 1989 May 8-11; Billings, MT. Washington, DC: Superintendent of Documents, U.S. Government Printing Office: 117-120.

Norton, B. E.; Tuhy, J.; Jensen, S. 1981. Riparian community classification for the Greys River, WY. Logan, UT: Utah State University, Department of Range Science. 188 p. Unpublished manuscript.

Padgett, Wayne G.; Youngblood, Andrew P.; Winward, Alma H. 1989. Riparian community type classification of Utah and southeastern Idaho. Region 4 Ecology 89-01. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 191 p.

Patten, D. T. 1963. Vegetational pattern in relation to environments in the Madison Range, MT. Ecological Monographs. 33: 375-406.

Pfister, Robert D. 1989. Ecological site classification in northern Rocky Mountain forests: putting theory to practice. In: Forestry on the frontier: proceedings; 1989 national convention. Washington, DC: Society of American Foresters. 444 p.

Pfister, Robert D.; Arno, Stephen F. 1980. Classifying forest habitat types based on potential climax vegetation. Forest Science. 26(1): 52-70.

Pfister, Robert D.; Kovalchik, Bernard L.; Arno, Stephen F.; Presby, Richard C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 175 p.

Platts, W. S.; Armour, C.; Booth, G. D.; Bryant, M.; Bufford, J. L.; Cuplin, P.; Jensen, S.; Lienkaemper, G. W.; Minshall, G. W.; Monsen, S. B.; Nelson, R. L.; Sedell, J. R.; Tuhy, J. S. 1987. Methods for evaluating riparian habitats with applications to management. Gen. Tech. Rep. INT-221. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 187 p.

Steele, Robert; Geier-Hayes, Kathleen. 1987. The Douglas-fir/elk sedge habitat type in central Idaho: succession and management. Boise, ID: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 111 p. Preliminary draft.

Steele, Robert; Pfister, Robert D.; Ryker, Russell A.; Kittams, Jay A. 1981. Forest habitat types of central Idaho. Gen. Tech. Rep. INT-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 138 p.

Szaro, Robert C. 1989. Riparian forest and scrubland community types of Arizona and New Mexico. Desert Plants. Vol. 9, Nos. 3-4. 138 p.

Tansley, A. G. 1935. The use and abuse of vegetational concepts and terms. Ecology. 16: 284-307.

Tiedeman, James A.; Francis, Richard E.; Terwilliger, Charles, Jr.; Carpenter, Len H. 1987. Shrub-steppe habitat types of Middle Park, Colorado. Res. Pap. RM-273. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 20 p.

Tuhy, Joel S.; Jensen, Sherman. 1982. Riparian classification for the Upper Salmon/Middle Fork Salmon Rivers, Idaho. Smithfield, UT: White Horse Associates. 200 p. Final Report.

U.S. Department of Agriculture, Soil Conservation Service. 1983. Range site technical guides for Montana. Bozeman, MT: Soil Conservation Service. ca. 750 p.

Windell, John T.; Willard, Beatrice E.; Cooper, David J.; Foster, Susan Q.; Knud-Hansen, Christopher F.; Rink, Lauranne P.; Kiladis, George N. 1986. An ecological characterization of Rocky Mountain montane and subalpine wetlands. Bio. Rep. 86(11). Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service, National Ecology Center, Division of Wildlife and Contaminant Research. 298 p.

Youngblood, Andrew P.; Padgett, Wayne G.; Winward, Alma H. 1985a. Riparian community type classification of northern Utah and adjacent Idaho. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 104 p. Preliminary draft.

Youngblood, Andrew P.; Padgett, Wayne G.; Winward, Alma H. 1985b. Riparian community type classification of eastern Idaho—western Wyoming. Region 4 Ecology 85-01. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 78 p.

Youngblood, Andrew P.; Mauk, R. L. 1985. Coniferous forest habitat types of central and southern Utah. Gen. Tech. Rep. INT-187. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 89 p.

245

PRELIMINARY RIPARIAN CLASSIFICATION SYSTEM FOR PRIVATE AND STATE-OWNED LANDS IN UTAH

Mark M. Petersen
David J. Somerville
Robert F. Sennett

ABSTRACT

A classification system for riparian areas in Utah was developed by the USDA Soil Conservation Service in cooperation with the Utah State Department of Agriculture and the Utah Riparian Management Coalition. The hierarchical system begins at the broad level of physiographic region and proceeds through the more specific levels of temperature regime, water chemistry, geologic district, associated aquatic ecosystem type, riparian complex, hydrologic moisture regime, range site, community type, and the present plant community.

INTRODUCTION

This riparian classification system has been developed by the USDA Soil Conservation Service in cooperation with the Utah State Department of Agriculture and the Utah Riparian Management Coalition.

Need for Classification System

The condition and health of riparian ecosystems is vital to the condition and health of Utah's watersheds. Riparian areas are critical areas for such resource values as water quality, wildlife habitat, fisheries, recreation, livestock grazing, water storage, and water yield.

Even though most of Utah is federally owned, most riparian areas in Utah are privately owned because of the way land was settled in Utah. Some important areas are owned by the State of Utah and some are owned by the Federal government. Federally owned riparian areas are managed by the Forest Service, U.S. Department of Agriculture, or the Bureau of Land Management, U.S. Department of the Interior.

Public interest in riparian area management has greatly increased over the past decade. This increased public interest has resulted from several factors including:

1. Increasing demand for good quality water.
2. Increasing competition between users.
3. Increasing interest in esthetic and wildlife values.
4. Increasing need for ecologically sound biotic inventories to assess environmental impacts.
5. Increasing interest in technology transfer among users, managers, and others benefiting from the many resource values associated with riparian areas.

A realistic and usable riparian classification system will be very valuable in meeting the needs resulting from these varied interests and activities, and will facilitate development of specific guidelines for use and management of the different types of riparian areas.

Classification Problems

Several conditions and factors make classification of riparian areas very difficult. Riparian areas have been extensively, and sometimes permanently, altered by the influence of humans. For example:

1. Widespread beaver trapping initiated changes in the hydrologic functioning of riparian areas and their associated streams.
2. Livestock grazing practices, which allowed livestock to concentrate foraging along the banks of streams, ponds, and lakes, have resulted in degradation of many riparian areas.
3. Concentrated recreational use has resulted in degradation of some riparian areas.
4. Weed control practices have resulted in elimination of forbs and woody vegetation from some riparian areas.
5. Overgrazing and other uses have resulted in poor hydrologic condition in some watersheds. This has caused unnatural and excessive runoff and unnaturally high peak flows, which have adversely impacted some riparian areas.
6. Dam construction on many streams and rivers has altered natural flows, lowered natural water tables, and reduced or eliminated flooding of the natural floodplain. These altered floodplains are now functioning more like stream terraces, and plant succession is toward upland community types rather than riparian community types.
7. Road construction and other developments have drastically altered many riparian areas and their associated aquatic ecosystems.

Riparian areas are difficult to classify because they are dynamic geomorphic units. Some riparian areas are undergoing constant change as a result of natural geomorphic processes. Within a mappable riparian area, there will exist a definable complex of different sites, but these sites tend to "move around" within the riparian area as the river "moves" and shifts within its floodplain.

Another condition that makes classification of riparian areas difficult is the fact that most plant species that grow in upland areas are also able to grow along drainages. This is further complicated by the continuum of changing species dominance as one proceeds up or down a drainage. Plant species that grow mostly in nonriparian environments at higher elevations may occur only in riparian areas at lower elevations.

The scale frequently used for mapping, inventorying, planning, etc., makes recognition of different sites in a riparian area impractical or impossible. Therefore, complexes of riparian sites are commonly mapped as inclusions within larger mapping units.

Terminology

Part of the difficulty in communicating about riparian ecosystems is in terminology and definitions. A search for a definition of riparian, riparian area, riparian zone, riparian system, riparian habitat, and riparian ecosystem revealed a state of confusion and inconsistency that makes meaningful communication almost impossible.

The Utah Riparian Management Coalition agreed on the following definition of a riparian area: "An area of land characterized and/or directly influenced by free or unbound water in the rooting zone. It has visible vegetation or physical characteristics reflective of permanent water influences. Lake shores and streambanks are typical riparian areas. Excluded are such sites as watercourses or washes that do not exhibit the presence of free or unbound water in the soil."

CLASSIFICATION CRITERIA

Riparian areas must possess three essential characteristics:

1. Soils
2. Hydrology
3. Vegetation Community

The following criteria have been developed for each of these three essential characteristics to aid in identifying and delineating riparian areas in the field:

Soils Criteria

Soils in natural riparian areas generally consist of stratified sediments that are subject to intermittent flooding or fluctuating water tables that may reach the surface. Riparian soils will typically have a water table with free water available for plant use within 60 inches of the soil surface at some time during the plant growing season.

Hydrology Criteria

Riparian areas are directly influenced by water from a watercourse or water body. This includes flooding and/or free water in the soil.

Vegetation Criteria

The riparian areas may be identified by the presence of, or potential under current physical conditions to support, vegetation communities that require, or tolerate, flooding and/or free water in the soil.

THE RIPARIAN CLASSIFICATION SYSTEM

The first level of the hierarchical classification system (fig. 1) is the physiographic region. Several publications delineating physiographic regions could be used. We suggest using the Major Land Resource Area (MLRA) as described in Agriculture Handbook 296, "Land Resource Regions and Major Land Resource Areas of the United States" (USDA 1981). MLRA's are delineated and described based on land use, elevation and topography, climate, water resources, soils, and potential natural vegetation. Thirteen MLRA's occur in Utah; however, only seven occur extensively:

D25 Owyhee High Plateau (minor area)
D28A Great Salt Lake Basin and Range
D28B Central Nevada Basin and Range (minor area)
D29 Southern Nevada Basin and Range (minor area)
D30 Sonoran Basin and Range (minor area)
D34 Central Desertic Basin and Plateaus
D35 Colorado Plateaus
D37 San Juan Valley Mesas and Plateaus (minor area)
D39 Arizona and New Mexico Mountains (minor area)
E47A Wasatch Mountains
E47B Utah Plateaus
E47C Uinta Mountains
E48A Southern Rocky Mountains

The second level of the system is temperature regime. Because riparian areas, by definition, receive moisture from free water in the soil and flooding, temperature is usually more of a limiting climatic factor than moisture. We have therefore chosen to use soil temperature regimes as the major climatic factor in classifying riparian ecosystems. Temperature regimes that occur in Utah are cryic, frigid, mesic, and thermic. Criteria for mapping each of these temperature regimes are described in "Soil Taxonomy" (USDA 1975).

The third level of the system is water chemistry of the ground water or the associated aquatic ecosystem. Because riparian vegetation associated with saline water is significantly different from that associated with fresh water, riparian ecosystems are divided by water chemistry into fresh water and saline water. We have chosen to use the same division as used by Cowardin and others (1979), which divides between fresh water and saline water at 0.5 parts per thousand.

PHYSIOGRAPHIC REGION - MAJOR LAND RESOURCE AREA

TEMPERATURE REGIME
   Cryic Temperature Regime
   Frigid Temperature Regime
   Mesic Temperature Regime
   Thermic Temperature Regime

WATER CHEMISTRY
   Fresh (<0.5 parts per thousand salt)
   Saline (>0.5 parts per thousand salt)

GEOLOGIC ZONE
   Valley Gradient
   Valley Shape and Bottom Width
   Bank Materials

ASSOCIATED AQUATIC ECOSYSTEM TYPE
   Stream (Riverine)
      Associated Stream Type
   Non-stream
      Lake (Lacustrine)
      Swamp (Palustrine)

RIPARIAN COMPLEX

HYDROLOGIC MOISTURE REGIME
   Hydroriparian
   Mesoriparian
   Xeroriparian

RANGE OR WOODLAND SITE
   (Potential or Climax Plant Community)

COMMUNITY TYPE (Present)

PRESENT PLANT COMMUNITY

Figure 1—The hierarchical framework for the Utah Riparian Classification System.

The fourth level of the system is geologic zone. The geomorphic features that seem to most strongly influence stream morphology are valley gradient, valley shape, valley bottom width, and bank materials, which are all strongly dependent on geologic weathering of the rock type.

The fifth level of the system is the type of aquatic ecosystem that is associated with the riparian area. This level separates stream-associated from non-stream-associated riparian areas. Stream-associated (riverine) areas are subdivided into stream types using the stream classification system developed by Rosgen (1985). Non-stream-associated areas include those influenced by lakes (lacustrine) and swamps (palustrine). Free water in the soil is usually aerobic when associated with a stream and anaerobic when associated with a swamp or lake.

The sixth level of the system is the riparian complex as described by Winward and Padgett (1988). A riparian complex represents a unit of land that supports, or may potentially support, a similar grouping of climax community types. Because the riparian complex is often the

smallest mappable unit, it is the level upon which most management decisions will be based. However, to facilitate a better understanding of riparian area ecology, the classification system further divides the riparian ecosystem into smaller ecological units.

The seventh level of the system is hydrologic moisture regime. Riparian ecosystems are divided into moisture regimes using terms hydroriparian, mesoriparian, and xeroriparian as described by Johnson and others (1984). We have slightly modified the definitions of these terms for this classification system.

Hydroriparian sites have hydric soils or substrata that are never or only briefly dry. They are usually associated with perennial water. Soils are seasonally flooded, as defined by Cowardin and others (1979), and are poorly to very poorly drained (USDA 1951). A water table usually occurs within 20 inches of the soil surface during most of the plant growing season. Vegetation consists of a predominance of obligate and facultative wet riparian plants.

Mesoriparian sites have nonhydric soils and substrata that are dry seasonally. They are usually associated with intermittent water or secondary floodplains of perennial streams. Soils are temporarily flooded, as defined by Cowardin and others (1979), and are somewhat poorly drained (USDA 1951). A water table usually occurs between 20 and 40 inches of the soil surface during at least part of the plant growing season. Vegetation consists of a predominance of facultative and facultative-upland with some faculative wet riparian plants.

Xeroriparian sites have moderately well-drained soils that are dry most of the plant growth period, but are provided with surface moisture or groundwater in excess of local rainfall. Soils may be intermittently flooded, as defined by Cowardin and others (1979), and are moderately well-drained (USDA 1951). A water table usually occurs between 40 and 60 inches of the soil surface during at least part of the plant growing season. Vegetation consists of a predominance of upland plants with some facultative plants.

The eighth level of the system is the range or woodland site. A range site is defined in the National Range Handbook (USDA 1976) as "a distinctive kind of rangeland that differs from other kinds of rangeland in its ability to produce a characteristic natural plant community." A range or woodland site is recognized and described on the basis of the physical environment of the site and the climax plant community it is capable of supporting.

The ninth level of the system is the present riparian community type. A riparian community type is "an abstract grouping of all riparian plant communities (stands) based on floristic and structural similarities in both overstory and undergrowth layers" (Manning and Padgett 1989).

The tenth level of the system is the present plant community.

Levels one through six of the classification system are based on factors that are relatively stable over time and are not subject to dramatic changes as a result of human-imposed influences or natural events such as catastrophic flooding. It is anticipated that much of the mapping of these levels can be accomplished by using Geographic

Information Systems (GIS). Levels seven through ten can be highly susceptible to human-imposed influences, such as overgrazing or road construction and natural events, such as major floods.

Each level in the hierarchical classification system can be aggregated to the next more general level so information can be extracted at various levels for different needs.

TESTING

This preliminary riparian classification system and criteria are being tested on riparian areas in several watersheds in Utah.

REFERENCES

Cowardin, L. M.; Carter, V.; Golet, F. C.; LaRoe, E. T. 1979. Classification of wetlands and deepwater habitats of the United States. FWS/OBS-79/31. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service. 103 p.

Johnson, R. R.; Carothers, S. W.; Simpson, J. M. 1984. A riparian classification system. In: California riparian ecosystems—ecology, conservation, and productive management. Berkeley, CA: University of California: 375-382.

Manning, M. E.; Padgett, W. G. 1989. Preliminary riparian community type classification for Nevada. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 135 p.

Rosgen, D. L. 1985. A stream classification system. In: Riparian ecosystems and their management—an interagency North American conference. Gen. Tech.

Rep. RM-120. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 91-95.

U.S. Department of Agriculture, Soil Conservation Service. 1951. Soil survey manual. Agric. Handb. 18. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 503 p. [Supplemented 1962].

U.S. Department of Agriculture, Soil Conservation Service. 1975. Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. Agric. Handb. 436. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 754 p.

U.S. Department of Agriculture, Soil Conservation Service. 1976. National range handbook. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. Section 302.1.

U.S. Department of Agriculture, Soil Conservation Service. 1981. Land resource regions and major land resource areas of the United States. Agric. Handb. 296. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 156 p.

U.S. Department of Agriculture, Soil Conservation Service. 1983. National soils handbook. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service.

Winward, A. H.; Padgett, W. G. Special considerations when classifying riparian areas. In: Ferguson, D. E.; Morgan, P.; Johnson, F. D., compilers. Proceedings—land classifications based on vegetation: applications for resource management; 1987 November 17-19; Moscow, ID. Gen. Tech. Rep. INT-257. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 176-179.

GROWTH AND YIELD OF WILLOWS IN CENTRAL OREGON COMPARED TO REPORTS IN WORLD LITERATURE

Bernard L. Kovalchik

ABSTRACT

Willows come in various shapes and sizes and respond in rates of growth and biomass accumulation to factors such as senescence, temperature, frost, flooding, soil nutrients, mineral toxicity, and fertilization. Height growth for naturally growing willows in central Oregon averages less than 1½ feet per year and decreases with age. Accumulated biomass may range from 4,000 to 60,000 pounds per acre dry weight on bogs and well-drained sites.

INTRODUCTION

A study describing riparian plant associations on the National Forests of central Oregon was completed in 1987 (Kovalchik 1987). Several of these plant associations were dominated by willows. Unfortunately, many of these willow-dominated sites have been degraded to less stable plant communities in response to improper management activities such as overuse by livestock.

Managers often wish to reestablish willows on degraded sites but lack information on willow establishment and growth responses to environmental factors. This paper summarizes world literature on willow growth and compares the information with willow growth in central Oregon.

GROWTH RESPONSES TO ENVIRONMENTAL FACTORS

Willow shoot growth varies from year to year, largely in response to the accumulation of resources during the previous year (Wijk 1986). Resource accumulation in turn depends on the length of growing season, which is determined by climatic variables such as length of previous year's snow cover, early season temperature, and drought (Wijk 1986). These conditions may have little visible effect on current season's growth, but may reduce shoot growth and rooting success the following year. Conditions during late-season bud development also affect the following year's shoot elongation (Kozlowski 1984).

Diurnal Climate

Willow height growth is most rapid during late afternoon and early evening and may be twice that of the rest of the

day (Dowsley 1987). Decreasing temperature and increasing humidity result in lower transpiration stress at this time of day. However, drought conditions and subsequent transpiration stress limit growth at all times of day.

Air Temperature

Much of the water taken in by a plant is passed through leaves as transpiration (Kramer and Kozlowski 1979). This benefits the plant through cooling of leaves and mineral translocation. However, on hot, dry days transpiration exceeds root absorption, resulting in rapid loss of water from leaves and twigs, increased water stress, stomatal closing, and ceasing of growth (Dowsley 1987; Kramar and Kozlowski 1979; Ogren and Oquist 1985). Exceedingly cold or hot temperatures also affect bud formation, dormancy, initiation, and expansion into shoots (Dowsley 1987). For these reasons, most plants of temperate North America find air temperature between 65 °F and 80 °F optimum for maximum photosynthetic rate (Larcher 1969).

Soil Temperature

Similarly, cold soil temperature reduces water absorption through roots and can result in transpiration stress and reduced growth, even on days with favorable air temperatures (Dowsley 1987; Fries 1943). Serious desiccation, and even death, of stems and leaves can occur with abnormally warm winter and spring temperatures on frozen or cold ground.

Frost

Willows are very tolerant of frost. Mature leaves and winter-dormant stems are capable of surviving temperatures of –4 °F and –94 °F, respectively (Sakai 1970). However, frosts during early growing season can cause severe damage to fast-growing shoots of willow (Christersson 1983; Fircks 1983). Temperatures of 28 °F or lower will kill the elongation zone soon after exposure. Frost-injured leaves and stems appear waterlogged and limp after thawing, and dry out rapidly. Exposure to hard frost (<23 °F) results in death immediately after thawing and may kill an entire season's shoot growth. Ice crystals do the actual damage. Lateral buds below the damaged shoot rapidly start to form new shoots.

Flooding

Willows are considered to be tolerant of flooding (Knighton 1981; Kozlowski 1984). The level of tolerance varies with the individual species' ability to tolerate various

soil and water conditions. Important willow adaptations to flooding include the formation of soft, spongy tissue (aerenchyma) for the transport of gases, enlargement of lenticals in stems to permit more efficient gas exchange, and regeneration of new roots (Kozlowski 1984). Willows tolerate low soil oxygen by their ability to transport large volumes of oxygen to roots through aerenchyma tissue. The roots in turn release oxygen into the soil and water atmosphere, indirectly benefiting plants by reducing toxic compounds, such as iron ions, and reducing the production of harmful gases produced by anerobic reduction (Kozlowski 1984).

Knighton (1981), in an experiment exposing willow to different levels of permanent flooding, showed willow growth was severely limited when the water level was at or above the root crown. Chlorotic foliage and some dead stems did not appear until the second season. Willow showed some growth if as little as 3 inches of soil was aerated, but was better in 6 inches or more of aerated soil.

The ability to regenerate new roots on the original root or submerged stem is important to willows (Kozlowski 1984). Elevated soil-water tables result in severely restricted root development, and eventual death of the root system. However, adventitious rooting above the flooded soil is abundant in many species of willow (except Scouler willow), and a new root system develops above the soil-water table (Knighton 1981).

Mineral and Chemical Toxicity in Flooded Soils

Many potentially fatal compounds such as soluble iron and manganese are produced by waterlogged soil (Kozlowski 1984). Ethanol, acetaldehyde, and cyanide compounds are produced by flooded roots. The many products of anerobic microsoil activity include methane, ethane, propylene, acids, aldehydes, ketones, and diamines. Kozlowski (1984) also reported increases in ethylene, auxins, and abseisic acid in flooded plants, chemicals that variously influence chemical and hormonal processes.

Therefore, wetland plants must have some mechanism for avoiding the toxicity of iron and manganese ions and other chemicals and minerals in flooded soils (Talbot and Etherington 1987). Willows from well-drained riparian soils express toxicity by reductions of growth, accumulation of iron in leaves, and failure to produce new roots when flooded. Roots of flood-tolerant willows immobilize iron and other toxic ions as part of a mechanism to avoid toxicity. This may suggest a site-based ranking of willows in central Oregon by tolerance to both flooding and mineral toxicity:

1. Scouler willow (*Salix scouleriana*), primarily an upland species, is least tolerant of flooded soils.
2. Whiplash willow (*S. lasiandra* var. *caudata*), Pacific willow (*S. lasiandra* var. *lasiandra*), coyote willow (*S. exigua*), and yellow willow (*S. lutea*)—found primarily on well-drained streambanks.
3. Bebb willow (*S. bebbiana*), restricted primarily to moist aspen stands, is never found on sites with long exposure to floods.
4. Geyer willow (*S. geyeriana* vars. *geyeriana* and *meliana*), Lemmon willow (*S. lemmonii*), Drummond willow

(*S. drummondiana*), and Sitka willow (*S. sitchensis*)—found on a wide variety of sites, ranging from well-drained streambanks and floodplains to wet shrub basins, but do poorly on bogs.
5. Booth willow (*S. boothii*) also grows on a wide variety of sites, but grows well in dwarf form on bogs.
6. Eastwood willow (*S. eastwoodiae*) and undergreen willow (*S. commutata*)—restricted largely to peat soils of bogs and higher elevation willow basins, indicating the most tolerance to both flooding and mineral toxicity.

Soil Nutrients

Walker and Chapin (1986) found higher rates of growth in more advanced successional stages compared to stands on newly colonized silt deposits. Fertilizing the silt soil resulted in an eightfold increase in total biomass, suggesting competition among willow seedlings for limited soil nutrients in early succession stages. The presence of nitrogen-fixing alder in more advanced succession stages results in a sixfold increase of exchangeable inorganic nitrogen compared to the silt deposits, yet the inhibiting effect of alder competition and shade resulted in reduced growth of willow.

Willows do not express good height growth on peat bogs. The soil is wet, pH 4 or below, and the mineral nutrient availability poor (Elowson and Rytter 1986). Bog soil contains considerable nitrogen, largely in unavailable organic form, and little or no P or K (Hytonen 1985). Soil bulk density is low and, coupled with high hydraulic conductivity, results in increased water and nutrients leaching out of the thin zone where roots do grow (Elowson and Rytter 1986). However, willows tolerate these low nitrogen levels by enhanced root growth and reduced height growth. Thus the plant may exploit a greater soil volume to sustain healthy dwarfed shoots (Good and Williams 1986).

Vesicular arbuscular mycorrhizae (VAM) occur on the roots of willows (Backhaus and others 1986). VAM fungi increase nutrient uptake by functioning as extended root systems. The benefits would be especially important in nutrient-poor soils such as peat and sand. However, Graw (1979) felt low pH associated with peat soils would inhibit VAM development on willows. VAM benefits would be less in clay and loam soils, which have large amounts of available nutrients and soil structure favorable for water storage, soil aeration, and nutrient exchange.

Fertilization

Europeans have considerable experience with fertilizing willow energy plantations. Plantations utilize draining, irrigating, and fertilizing to increase biomass production in planted willow stands. Growth of willows on unfertilized peat and sand soils is slow (Christersson 1986; Hytonen 1985). The application of wood ash increases soil pH from 4.9 to 5.5, which results in increased microbial activity, organic nitrogen mineralization, and nitrogen availability (Weber and others 1985) with a subsequent increase in the willow harvest of 65 to 70 percent. Adding ammonium nitrate to peat soils results in increased shoot growth, leaf weight, shoot-to-root ratio, and aboveground biomass (Good

and Williams 1986). However, treatment with urea increases the acidity of peat soils, counteracting any beneficial effects (Hytonen 1985).

GROWTH RESPONSES TO NONENVIRONMENTAL FACTORS

Ungulate Browsing

Ungulate browsing and beaver cutting immediately reduce height growth of willows by damaging and killing stems. Smith (1980) and Kindschy (1990) found that less than half of heavily clipped or browsed willow stems survive into the following year, even with protection from browsing. Of the survivors, regrowth was half the growth of ungrazed stems. Therefore, it may take 3 or more years for heavily browsed willows to recover from browsing by domestic or wild ungulates.

Insects

Managers often overlook damage done by willow insect pests. The following types of willow damage are caused by insects (West 1985):

Defoliating. Leaf-eating is done by grasshoppers, spanworms, the larvae of moths, butterflies, and larval and adult beetles. Defoliation of a plant reduces the photosynthetic capacity of the plant. The effect of normal infestations on a willow's growth may be negligible.

Mining. Leaf miners include a diverse group of insects such as flea beetles, leaf miners, and casebearers. The tiny larvae of these insects live in the leaf epidermis, causing irregular blotches or tunnels as they consume the leaf tissue. Damage is usually minor.

Wood boring. Borers cause damage by slowing growth or killing attacked portions of the willow. In addition, the tunnelling activity weakens shoots so that wind or snow breaks them. Attack often stimulates the growth of lateral branches, thus compensating for the destruction of shoots.

Leaf and stem galling. Galling insects cause immature leaf and stem tissues to form swollen structures that provide the insect with food and shelter at the expense of the rest of the plant. Stem gallers may girdle stems and result in the direct death of the shoot. Damage from leaf gallers is minimal.

Sapsucking. Sapsucking insects include the psyllids, aphids, scale insects, and mites. Sapsucking reduces the carbohydrate reserves of the willows. Injury due to sapsucking is usually minor.

Age

All plants experience decreases in height growth with age (Kozlowski 1984). Yearly decreases in shoot growth are partially due to nutrient and water deficiencies arising from restricted root growth, or may be due to reductions in xylem and phloem formation with age. Additionally, respiration burden and translocation resistance increases with the height and spread of the plant, thus requiring larger

energy expenditures (Wijk 1986). An increase of 5 years in age may correspond to a reduction in average shoot growth of 50 percent.

GROWTH AND YIELD FROM PUBLISHED REPORTS

Height Growth

Height growth is dramatic in the controlled, enhanced environments of energy plantations. Christersson (1983) reported 9 to 12 feet total height growth in a 2-year-old energy plantation in Sweden. In another Swedish study, Dowsley (1987) reported willow heights of 5½ to 6½ feet at the end of the first growing season. Robertson (1986) did not report height growth for energy plantations in Newfoundland, but photographs of a first-year plantation showed 6 to 8 feet of growth. Hybrid clones may grow 50 percent faster than either parent (Hathaway 1987). Data are not available for natural stands.

Radial Growth

The ultimate size of willow stems depends on the willow species and the characteristics of the site. Walker (1987) showed strong correlation between summer temperature regimes and growth ring width on floodplains along the north slope of Alaska. Elevation, soil moisture, wind, and nutrients also affect radial growth. Radial growth decreases with age and beyond 10 years cannot be strongly correlated with any environmental factor. In bog and tundra environments, cold soil temperatures and low nutrient availability are likely more limiting to radial growth than air temperature (Walker 1987). Data were not available for energy plantations.

Biomass Distribution

Thilenius (1990) reported unbrowsed twigs of Alaska willow (*Salix barclayi*) growing as gently tapering cylinders along the coast of Alaska. The distal one-half of the twigs contained only 35 to 41 percent of the total weight of the current year's growth. Implications are that a browsed willow with one-half of its twigs used to one-half of their length would look heavily used. Yet, less than 20 percent of the weight of the current year's growth is used. His study did not account for browsed twigs dying back to the next lower stem bud, as I have observed them to do.

Cannell and others (1988) reported willow biomass distributed 24 percent to leaves, 42 percent to stems, and 33 percent to roots on well-drained soils. At the beginning of the growing season, 40 to 50 percent of the dry matter production went into leaves, setting the stage for later biomass production through apical elongation and meristematic expansion. Dry, aboveground biomass for Alaska willow was proportioned 25 to 30 percent in the leaves and 70 to 75 percent in the stems (Thilenius 1988). Reader and Stewart (1972) reported 75 percent of the yearly net above- and belowground production for bog willows was in roots,

indicating a high root ratio for willows in bogs compared to well-drained soils typical of tall willow stands.

Biomass Production

Cannell and others (1987) reported daily increments of 380 pounds aboveground biomass per acre per day during peak production periods (mid-June through mid-August) and an average of 176 pounds per acre per day for the entire growing season in an energy plantation in Scotland. Total seasonal biomass production was 9,700 pounds per acre aboveground, of which 7,300 pounds occurred in stems and 2,400 pounds in leaves.

Eckersten and others (1987) found considerable variation in the biomass production of willow clones planted in energy plantations in Sweden. The mean annual production of aboveground biomass averaged 6,961 dry pounds per acre for all sites. Variation between locations reflected variability in temperature and radiation climate. The coastal sites had less variation due to the buffering effect of coastal climate. Even higher production of 23,100 pounds per acre dry aboveground matter was reported for a first-year plantation in Newfoundland (Robertson 1986). Another Swedish energy plantation yielded a total aboveground biomass of 11,700 dry pounds per acre, of which 7,770 pounds was for stems and 3,400 pounds for leaves in the first season after planting (Nilsson and Ericsson 1986). The second year yielded 17,500 pounds, with 10,800 pounds of stems and 6,700 pounds of leaves. Production was higher the second year due to larger root systems, larger initial nutrient stores, and buds ready to sprout.

Biomass production in natural willow stands is lower than in energy plantations. Accumulated aboveground biomass ranged from 10,000 dry pounds per acre in a bog to 30,000 pounds in a tall willow stand in Alaska (Reader and Stewart 1972). Shrub biomass in mixed willow, alder, and birch wetlands in Minnesota ranged from 446 to 59,000 pounds per acre (Connolly-McCarthy and Grigal 1985). Total biomass averaged 5,442 pounds per acre on bogs and 12,000 pounds per acre on well-drained peat, while marshes with mineral soil averaged 9,900 pounds per acre. Thus production differences between strikingly different soil classes were not that great, indicating factors other than soil classification have a greater effect on shrub biomass production. For instance, soils with lower water tables support much greater biomass than similar soils with high water tables. Elsewhere, estimated accumulated biomass for alder-willow stands on alluvial soil in central Alaska ranged from 9,000 pounds per acre for 5-year-old stands to 43,000 pounds for 20-year-old stands (Van Cleve and others 1971).

GROWTH AND YIELD OF NATURAL WILLOW STANDS IN CENTRAL OREGON

Stems of willows were destructively sampled in conjunction with the development of the riparian plant association classification for central Oregon (Kovalchik 1987). One prominent, healthy stem was selected from the center of a willow clump and cut into 1-foot sections. Diameters and ages were measured in the office and used to develop height/age curves for the common willows of central Oregon. Results are discussed here.

Growth Form

Willows in central Oregon vary considerably in size and shape. Geyer, Lemmon, Booth, Sitka, Eastwood, and undergreen willows all form broadly rounded, many-stemmed shrubs on well-drained soils. Booth, Eastwood, and undergreen willows also form dwarf (less than 2 feet tall), few-stemmed shrubs on bogs. Yellow, Pacific, whiplash, Bebb, and Scouler willow grow as tall, several-stemmed shrubs or small trees with one or more trunks.

Root Growth

The numerous stems of Geyer willow arise from a single root caudex (author's observation). Several main roots branch off this caudex into numerous horizontal roots that extend considerable distances from the plant. New root systems may develop by adventitious rooting of stems forced into contact with the ground by snow loading. The root caudex may grow for at least 50 years.

Total age of Geyer and similar willows may be many centuries because of the ability of willows to regenerate new root systems in response to disease, injury, or changing soil-water tables. Coyote willow is the only willow in central Oregon that forms large clones by sprouting from root runners.

Height Growth

Height/age comparisons from sectioned stems of common willows are shown in figure 1. Curves are for well-drained sites, except Eastwood willow is shown for both well-drained peat and poorly drained bog soils. Annual rate of height growth ranged from several inches to 1½ feet per year in the first 10 years of growth. Lemmon willow shows the fastest height growth, averaging 15 feet at 10 years and 17 feet maximum height at 15 years. Geyer willow is slightly slower in growth, averaging 12 feet at 10 years and 15 feet at 18 years. Booth willow averages 8 feet at 10 years and 10 feet at 16 years on well-drained soils. Eastwood willow height growth reflects higher elevations and cold soils. Mature shrubs are about 6½ feet tall at 10 years and 7 feet at 13 years on well-drained peat, but average only 2 feet in height at 10 years on bogs. Undergreen willow grows similarly to Eastwood willow on well-drained peat. Both undergreen and Booth willows grow like Eastwood willow on bogs.

Basal Diameter

Basal diameter for willows in central Oregon ranged from:

- 0.8 to 2.25 inches for 11- to 21-year-old Lemmon willow.
- 0.5 to 2.05 inches for 10- to 21-year-old Geyer willow.
- 0.8 to 1.7 inches for 10- to 20-year-old stems of Booth willow.
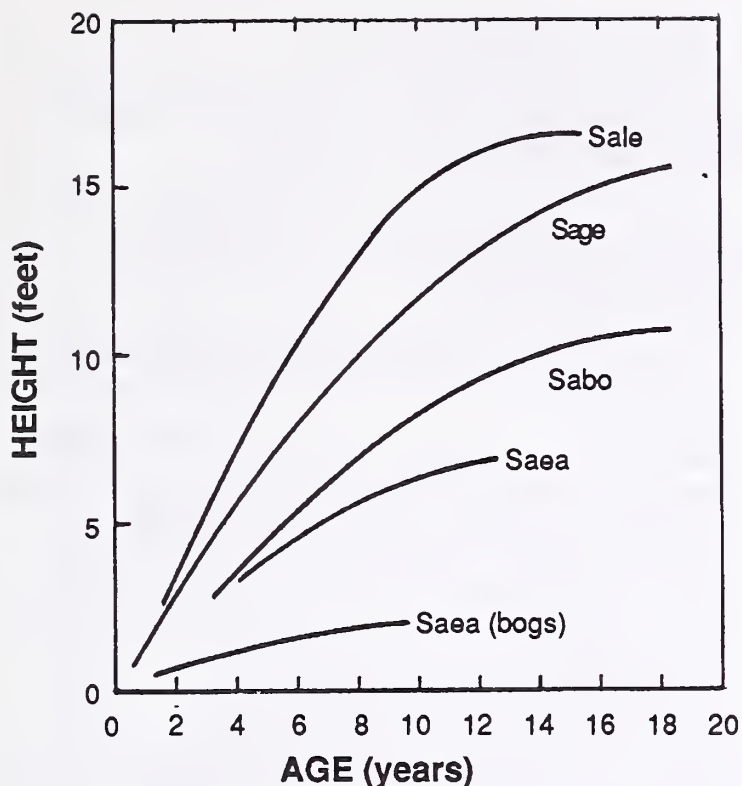
Figure 1—Height/age comparisons for some important willows in central Oregon. Sale = *Salix lemmonii* on well-drained sites ($n = 35$, $R^2 = 0.97$, $Y = 2.211X - 0.074X^2$); Sage = *Salix geyeriana* on well-drained sites ($n = 234$, $R^2 = 0.87$, $Y = 1.534X - 0.078X^2$); Sabo = *Salix boothii* on well-drained sites ($n = 103$, $R^2 = 0.77$, $Y = 1.126X - 0.030X^2$); Saea = *Salix eastwoodiae* on well-drained sites ($n = 67$, $R^2 = 0.79$, $Y = 0.984X - 0.035X^2$); Saea (bogs) = *Salix eastwoodiae* on peat bogs ($n = 9$, $R^2 = 0.15$, $Y = 0.414X - 0.022X^2$).

• 0.2 to 0.9 inches for 5- to 13-year-old Eastwood willow on well-drained peat.

• 0.2 to 0.4 inches for 5- to 10-year-old Eastwood willow on bogs.

Stem Age

Maximum stem ages vary considerably between species of willows. Stems of Geyer, Lemmon, and Booth willows on well-drained soils approach senescence between the ages of 15 to 20 years and die due to attacks by insects or disease (author's observation). Dead stems often resprout from adventitious buds from near the base of the stem, and grow to replace the dead stem. The same age pattern occurs for Eastwood and undergreen willows on well-drained peat soil, but at 10- to 15-year intervals. On bogs, stem ages for Eastwood, undergreen, and Booth willows were not observed to exceed 10 years. Total shrub age is much greater due to

continuous regeneration of roots and stems (author's observation). All age classes should be present on healthy, vigorous willows.

Biomass Distribution

Biomass distribution information was not collected for central Oregon willows, but is probably similar to information shown in figure 2.

CONCLUSIONS

Rates of growth for willows in central Oregon are much less than reported for energy plantations in Eurasia and Newfoundland. Willows on bogs grow only a few inches in height per year and mature plants average less than 2 feet tall. Basal stem diameters are less than 0.4 inches. Willows on well-drained soils average less than 1½ feet annual height growth. Depending on species, mature shrubs grow to 7 to 17 feet with basal diameters of 0.9 to 2.15 inches. For comparison, willows on energy plantation grew 4½ to 8 feet the first year (Christersson 1986; Dowsley 1987; Robertson 1986).

Total shrub biomass in central Oregon may be similar to that reported for natural stands in Alaska and Minnesota (Connolly-McCarthy and Grigal 1985; Van Cleve and others 1971). If so, they would accumulate about 4,000 to 6,000 pounds per acre dry weight on peat bogs and 40,000 to 60,000 pounds per acre on well-drained soils. The general distribution of aboveground biomass should approximate 25 to 30 percent in the leaves and 70 to 75 percent in the stems (Thilenius 1988). Roots should comprise about one-third of the total shrub biomass (Cannell and others 1988) on well-drained soils and 75 percent on bogs (Reader and Stewart 1972).

Figure 2—Biomass distribution on shrubby willow (Cannell and others 1988; Reader and Stewart 1972; Thilenius 1988).

REFERENCES

Backhaus, G. F.; Haggblom, P.; Nilsson, L. O. 1986. The influence of vesicular-arbuscular mycorrhizae on biomass production in willow. Canadian Journal of Forest Research. 16(1): 103-108.
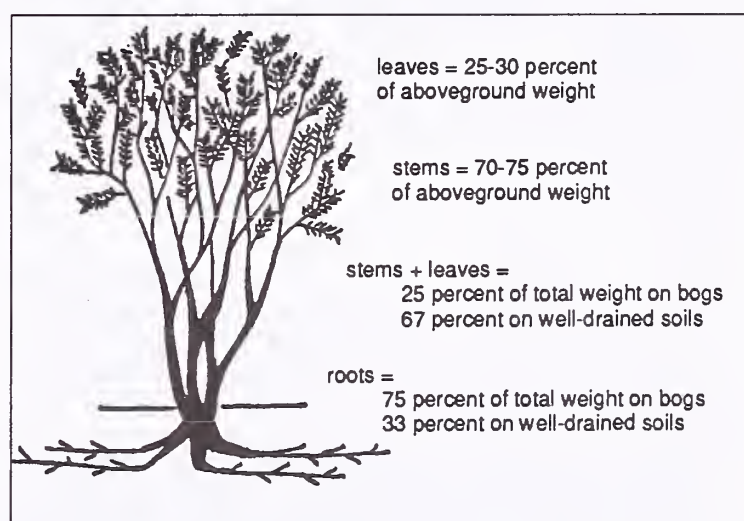
Cannell, M. G. R.; Milne, R.; Sheppard, L. J.; Unsworth, M. H. 1987. Radiation interception and productivity of willow. Journal of Applied Ecology. 24: 261-278.

Cannell, M. G. R.; Sheppard, L. J.; Milne, R. 1988. Light use efficiency and woody biomass production of poplar and willow. Journal of the Institute of Chartered Foresters. 61(2): 125-136.

Christersson, L. 1983. Frost damage during the growing season. In: Plant production in the north workshop: proceedings; September 4-9; Tromso, Norway: 191-198.

Christersson, L. 1986. High technology biomass production by Salix clones on a sandy soil in southern Sweden. Tree Physiology. 2: 261-272.

Connolly-McCarthy, B. J.; Grigal, D. F. 1985. Biomass of shrub-dominated wetlands in Minnesota. Forest Science. 31(4): 1011-1017.

Dowsley, B. 1987. Study of the correlation of diurnal growth patterns to climatic variables in a Salix energy plantation. Newfoundland Forest Research Center Information Report N-X-260. Canadian Forestry Service. 28 p.

Eckersten, H.; Lindroth, A.; Nilsson, L. 1987. Willow production related to climatic variations in Southern Sweden. Scandinavian Journal of Forest Research. 2: 99-110.

Elowson, S.; Rytter, L. 1986. Soil characteristics of raised sphagnum bog in relation to intensively grown deciduous species. Scandinavian Journal of Forest Research. 1(1): 95-111.

Fries, N. 1943. On the winter water regime of broadleaved trees. Svensk Botan Tidskrift. 37: 241-265.

Good, J. E. G.; Williams, T. G. 1986. Growth responses of selected clones of birch (Betula pendula Roth., B. pubescens Ehrh.) and willow (Salix caprea L., S. cinerea L.) to nitrogen in solution culture. Plant and Soil. 92(2): 209-222.

Graw, D. 1979. The influence of soil pH on the efficiency of vesicular-arbuscular mycorrhizae. New Phytology. 82: 687-695.

Hathaway, R. L. 1987. Willows for the future. New Zealand Soil Conservation Centre 53. 4 p.

Hytonen, J. 1985. Stability of various phosphorus and nitrogen fertilizers for fertilizing willow stands on cut-over peatlands. In: Bioenergy 84: the proceedings of an international conference on bioenergy. Goteborg, Sweden: Elsevier Applied Science. 2: 114-118.

Knighton, M. D. 1981. Growth response of speckled alder and willow to depth of flooding. Res. Pap. NC-198. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 5 p.

Kovalchik, B. L. 1987. Riparian zone associations: Deschutes, Ochoco, Fremont, and Winema National Forests. R6-ECOL-TP-279-87. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 171 p.

Kozlowski, T. T. 1984. Plant responses to flooding of soil. BioScience. 34(3): 162-167.

Kramer, P. J.; Kozlowski, T. T. 1979. Physiology of woody plants. London: Academic Press.

Larcher, W. 1969. The effect of environment and physiological variables on the carbon dioxide gas exchange of trees. Photosynthetica. 3: 167-198.

Nilsson, L. O.; Ericsson, T. 1986. Influence of shoot age on growth and nutrient uptake patterns in a willow plantation. Canadian Journal of Forest Research. 16(2): 185-190.

Reader, R. J.; Stewart, J. M. 1972. The relationship between net primary production and accumulation for a peatland on southeastern Manitoba. Ecology. 53(6): 1025-1037.

Robertson, A. 1986. Boreal plantation R & D with Salix species: Proceedings of the sixth international workshop on forest regeneration. Gen. Tech. Rep. PNW-194. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 27-30.

Sakai, A. 1970. Freezing resistance in willows from different climates. Ecology. 51: 485-491.

Shaver, G. R. 1986. Woody stem production in Alaskan tundra shrubs. Ecology. 67(3): 660-669.

Smith, B. H. 1980. Riparian willow management: its problems and potentials, within the scope of multiple use management. Presented to: University of Wyoming—Shrub Ecology Workshop. 1980 June 5-6; Lander, WY. 15 p. Unpublished report.

Talbot, R. J.; Etherington, J. R. 1987. Comparative studies of plant growth and distribution in relation to water-logging. The New Phytologist. April: 575-583.

Thilenius, J. F. 1988. Weight distribution in the current annual twigs of Barclay willow. Res. Note PNW-472. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 10 p.

Thilenius, J. F. 1990. Dimensional weights and forage quality of Barclay willow and sweetgale on moose ranges in the wetlands of the Copper River Delta, Alaska. Forest Ecology and Management. 33/34(1-4): 463-483.

Van Cleve, K.; Viereck, L. A.; Schlenter, R. L. 1971. Accumulation of nitrogen in alder (Alnus) ecosystems near Fairbanks, Alaska. Arctic and Alpine Research. 3: 101-114.

Walker, L. R.; Chapin, F. S. 1986. Physiological controls over seedling growth in primary succession on an Alaskan floodplain. Ecology. 67(6): 1508-1523.

Walker, D. A. 1987. Height and growth rings of Salix lanata ssp. richardsonii along the coastal temperature gradient of northern Alaska. Canadian Journal of Botany. 65(5): 988-993.

Weber, A.; Karsisto, M.; Leepanen, R.; Sundman, V.; Skujins, J. 1985. Microbial activities in a histisol: effects of wood ash and NPK fertilizers. Soil Biology and Biochemistry. 17(3): 291-296.

West, A. 1985. A review of insects affecting production of willows. Newfoundland Forest Research Center Information Report N-X-232. Canadian Forestry Service. 82 p.

Wijk, S. 1986. Influence of climate and age on annual shoot increment in Salix herbacea. Journal of Ecology. 74(3): 685-692.

245

EFFECTS OF CATTLE GRAZING ON SHOOT POPULATION DYNAMICS OF BEAKED SEDGE

Douglas R. Allen
Clayton B. Marlow

ABSTRACT

More information is needed on the grazing responses of wetland graminoids to improve management of riparian shrub community types. To study the effect of cattle grazing on the number of new shoots produced by beaked sedge (Carex rostrata) *within the 1989 and 1990 growing seasons, 40 plots were protected and 40 plots were grazed by cattle in June and September each year. Although number of shoots produced on grazed and ungrazed plots were similar in 1989, grazed plots produced 27.4 percent more shoots per plot than ungrazed plots* (P < 0.05) *in 1990. Preliminary analysis of monthly shoot production data indicates that the greatest difference between grazed and ungrazed plots was in July. Seasonal mortality on grazed and ungrazed plots was similar, although high rodent-caused mortality in the ungrazed plots may have masked the effects of cattle grazing.*

INTRODUCTION

Riparian plant communities comprise only 1 to 2 percent of the total land area of the Western United States, but provide a disproportionately greater amount of cover and forage for wildlife and livestock. Although most riparian forage is produced by rhizomatous grasses in moist or wet soils, most grazing strategies have been developed for upland ranges dominated by cespitose graminoids in water-limited soils. The extent to which grazing response models produced for upland sites can be applied successfully to riparian sites is limited.

Beaked sedge (*Carex rostrata*) is widely distributed in temperate climates and is a dominant herbaceous component of willow communities in the Northern Rocky Mountains (Hansen and others 1988; Kovalchik 1987). Although beaked sedge has been described as moderately palatable to cattle and moderately tolerant of grazing (Hermann 1970; Ratliff 1983) the species may be invaded or replaced by other riparian graminoids when subjected to prolonged heavy grazing. Information about how populations of beaked sedge respond to grazing by cattle would be useful in developing grazing strategies in riparian plant communities.

Beaked sedge shoots have a biennial growth cycle with low survivorship to maturity (Bernard and Gorham 1978). Although total shoot numbers may vary considerably within a growing season, population numbers tend to remain relatively stable from year to year (Bernard 1976; Gorham and Somers 1972). High mortality is compensated for by the initiation of new shoots, with peak emergence in late summer (Bernard 1976; Bernard and Hankinson 1979; Gorham and Somers 1972).

Beaked sedge is strongly rhizomatous (Bernard and Gorham 1978), which allows for translocation of nutrients and water between shoots. Defoliated shoots can be subsidized by other connected shoots, or dormant buds can be stimulated by defoliation to initiate new shoot growth (Jonsdottir and Callaghan 1989). Although the apical growing points of beaked sedge remain low during the vegetative stage, leaf meristems of the sedges are typically less developed than other rhizomatous graminoids (Cronquist 1981). Thus defoliated leaves regrow slowly and nutrients may be translocated to shoot buds rather than to leaf growing points.

The removal of tall dense standing material increases soil insolation and soil temperatures. These conditions contribute to the stimulation of leaf regrowth and the initiation of new shoots from buds on rhizomatous graminoids (Jewiss 1972; Parsons and others 1984).

Using information from these studies we hypothesized that cattle grazing will increase the number of new shoots produced by beaked sedge in a growing season. We also wanted to determine when, by month, differences in the number of new shoots produced would occur within a growing season.

METHODS

The study area lies along an upper reach of Cottonwood Creek in the Montana Agricultural Experiment Station's Red Bluff Research Ranch in southwestern Montana. Elevation is about 1,700 m, and the site receives about 460 mm annual precipitation. We used a population dynamics approach rather than determining biomass production because population ecology is typically a better measure of ecological status. Biomass production is highly variable and subject to seasonal and annual fluctuations in water level (Hultgren 1989). Beaked sedge mortality and natality occurs throughout the year, thus clipping and weighing once or twice within a growing season excludes shoots that die between cuttings or seasons, resulting in an underestimation of total forage production (Bernard and Gorham 1978). In a grazing study, the weight of forage produced

in grazed plots would have to be estimated; population dynamics can be directly and continuously monitored.

We chose grazing over a clipping treatment because we wanted to study the response of beaked sedge in the field, and we felt that intrinsic differences between grazing and clipping might affect the applicability of our results to natural systems (Jameson 1963). Defoliation pattern, selectivity, trampling, and nutrient cycling may all be important factors that would be excluded in a clipping treatment.

We conducted the study in an eight-paddock grazing system established along Cottonwood Creek in 1986. We used a block design, selecting four beaked sedge-dominated stands located in four of the paddocks. Eighty 400-cm² round plots were systematically distributed among the blocks and were the experimental units. Forty plots were established in the grazed portion of the stands and 40 plots were protected by 1.0-m-diameter cages. Stands were grazed in late June and mid-September of 1989 and 1990 by 12 cow/calf pairs until utilization of the riparian vegetation reached 60 to 80 percent. All existing shoots were marked with red wires in June 1989, and all emerging shoots in subsequent months were marked with wires of different colors. Mortality was also measured monthly within each plot and wires of dead shoots were removed. Basal groundcover of competing vegetation, soil penetration resistance, initial shoot counts, and rodent-caused mortality were used as covariates in the statistical analysis.

We estimated sample adequacy from a preliminary sample of 10 randomly placed plots in spring of 1989. We determined that we should be able to detect a 10 percent difference between two treatment means of total shoots per plot at $P < 0.10$ with 40 plots per treatment. We used the SAS General Linear Model procedure for Analysis of Variance (with covariates) for monthly and cumulative new shoots and mortality for 1989 and 1990. A square-root transformation was used for our data, which is typical for counting data with a Poisson distribution (Sokol and Rolf 1981). We used the Block*Treatment Mean Square Error combined with Model Error for the error term in the tests of significance, and back-transformed the Least Square (LS) Means when presenting treatment means. Confidence intervals were determined by multiplying the LS Standard Error by the "t" value ($P < 0.05$, 3 df) and squaring the differences.

RESULTS

In 1989 the grazed and ungrazed plots produced similar numbers of total new shoots (fig. 1). In 1990 the grazed plots produced 27 percent more total new shoots than the ungrazed plots ($P < 0.05$). A preliminary summary of monthly new shoot data indicated that the greatest difference between grazed and ungrazed plots was in July following the June grazing period (fig. 2). Grazed plots produced 15 percent more new shoots than ungrazed plots in July 1989, and produced 10 percent more new shoots than ungrazed plots in July 1990. We expect to be able to detect about a 10 percent difference in new shoots produced per month.

Shoot mortality in 1989 was lower than in 1990 (fig. 3), mainly because we monitored shoots only from July through September in 1989, but we monitored shoots from April
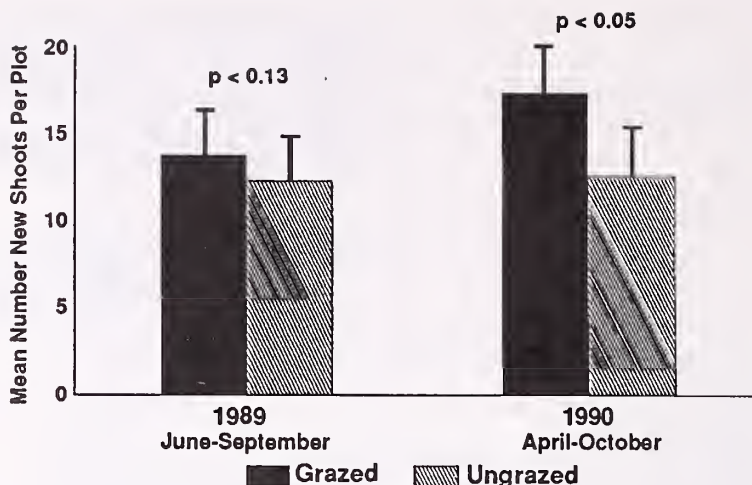
Figure 1—Mean number of new shoots produced per plot during 1989 and 1990.
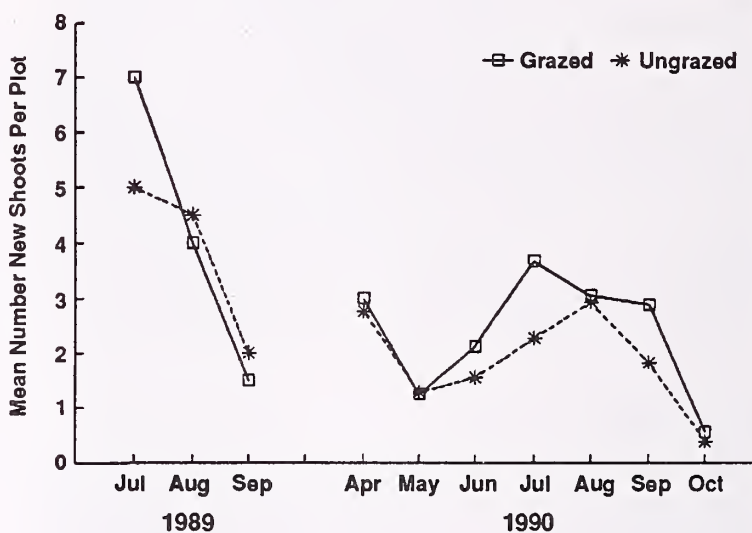
Figure 2—Mean number of new shoots produced monthly per plot in 1989 and 1990.

through October in 1990. In 1989 the first grazing treatment began in late June, which has historically been the turn-on date for the Cottonwood Creek pasture at Red Bluff. Consequently, monitoring plots prior to grazing in spring of 1989 would not have been useful in determining the effects of our treatment. Although 1989 mortality was different between grazed and ungrazed plots ($P < 0.01$), this result is probably not biologically meaningful because of the low totals. Mortality was similar between grazed and ungrazed plots in 1990, although this result was strongly affected by rodent-caused mortality, which was significant as a covariate in 1990. Meadow voles (*Microtus pennsylvanicus*) and deer mice (*Peromyscus maniculatus*) were the most common rodent grazers in the beaked sedge stands. Rodents killed shoots mainly by removing stem bases, crowns, and roots. Rodent-caused mortality was highly variable, but was greater in the ungrazed plots in 1990. Accordingly, the effects of the cattle grazing treatment may have been masked in 1990.
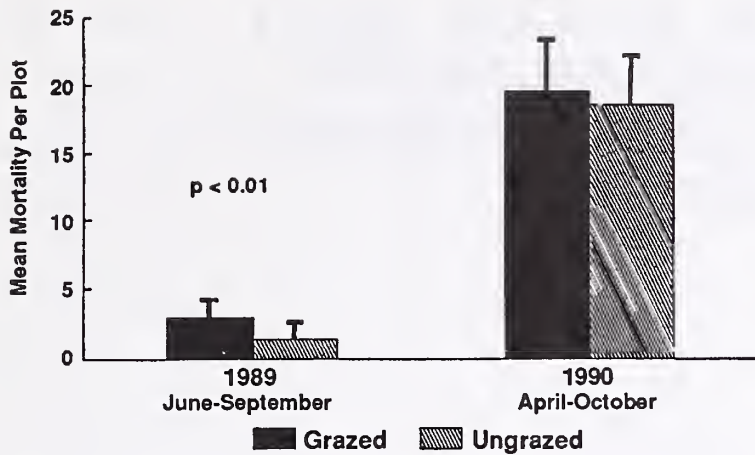
Figure 3—Mean mortality of shoots per plot during 1989 and 1990.

DISCUSSION

In 1989 grazing did not affect new shoot production of beaked sedge shoots, although in 1990 grazing increased the number of new shoots produced in grazed plots compared with ungrazed plots. Most of this difference was accounted for during the rapid growth period (July) following the June grazing treatment. These results provide strong evidence to support our hypothesis that grazing by cattle affects shoot population dynamics of beaked sedge in our study area. Our results support findings in the literature that rhizomatous forages and forages with low growing points during the vegetative stage are grazing tolerant. For beaked sedge, however, grazing tolerance appears to be more a function of increased initiation of new shoots than one of regrowth of existing leaves. Our results also support findings that removing standing material, particularly on rhizomatous graminoids, stimulates the initiation of new shoots.

Trends in mortality, and consequently net population trends, are not yet apparent from our results, partly due to the confounding effect of rodent-caused mortality, primarily on ungrazed plots. Our data tend to support the findings of Gorham and Somers (1972) that overwinter and late summer are the periods of greatest shoot mortality.

Grazed beaked sedge stands in the Cottonwood Creek drainage seem to be able to maintain or increase population numbers by increasing the production of new shoots to replace mortality during a growing season. Given an adequate regrowth period, beaked sedge should be tolerant of moderate to heavy, controlled early summer and fall grazing in southwestern Montana willow/beaked sedge communities similar to our study area.

We plan to collect monthly data in April, May, and June of 1991. These additional data will give us two 12-month sampling periods, or 2 years of treatment effects, which roughly equals the life span of a beaked sedge shoot. These data will help us to further assess total mortality and net population changes.

REFERENCES

Bernard, J. M. 1976. The life history and population dynamics of shoots of *Carex rostrata*. Journal of Ecology. 64: 1045-1048.

Bernard, J. M.; Gorham, E. 1978. Life history aspects of primary production in sedge wetlands. In: Good, Ralph E., ed. Freshwater wetlands: ecological processes and management potential. New York: Academic Press: 39-51.

Bernard, J. M.; Hankinson, G. 1979. Seasonal changes in standing crop, primary production, and nutrient levels in a *Carex rostrata* wetland. Oikos. 32: 328-336.

Cronquist, A. 1981. An integrated system of classification of flowering plants. New York: Columbia University Press. 1262 p.

Gorham, E.; Somers, M. G. 1972. Seasonal changes in the standing crop of two montane sedges. Canadian Journal of Botany. 51: 1097-1108.

Hanson, P. L.; Chadde, S. W.; Pfister, R. D. 1988. Riparian dominance types of Montana. Missoula, MT: Montana Riparian Association. 411 p.

Hermann, F. J. 1970. Manual of the carices of the Rocky Mountains and Colorado Basin. Agric. Handb. 374. Washington, DC: U.S. Department of Agriculture, Forest Service. 397 p.

Hultgren, A. B. C. 1989. Growth in length of *Carex rostrata* Stokes shoots in relation to water level. Aquatic Botany. 34: 353-365.

Jameson, D. A. 1963. Responses of individual plants to harvesting. Botanical Review. 11: 532-594.

Jewiss, O. R. 1972. Tillering in grasses—its significance and control. Journal of the British Grassland Society. 27: 65-82.

Jonsdottir, I. S.; Callaghan, T. V. 1989. Localized defoliation stress and the movement of ^{14}C-photoassimilates between tillers of *Carex bigelowii*. Oikos. 54: 211-219.

Kovalchik, B. L. 1987. Riparian zone associations: Deschutes, Ochoco, Fremont, and Winema National Forests. R6 Ecol TP-279-87. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 171 p.

Parsons, A. J.; Collett, B.; Lewis, J. 1984. Changes in the structure and physiology of a perennial ryegrass sward when released from a continuous stocking management: implications for the use of exclusion cages in continuously stocked swards. Grass and Forage Science. 39: 1-9.

Ratliff, R. D. 1983. Nebraska sedge (*Carex nebraskensis* Dewey): observations on shoot life history and management. Journal of Range Management. 36(4): 429-430.

Sokol, R. R.; Rohlf, F. J. 1981. Biometry: the principles and practice of statistics in biological research. 2d ed. New York: W. H. Freeman. 859 p.

245

REDUCTION OF WILLOW SEED PRODUCTION BY UNGULATE BROWSING IN YELLOWSTONE NATIONAL PARK

Charles E. Kay
Steve Chadde

ABSTRACT

Reports results of a study of the impact that native ungulates had on the production of willow (Salix bebbiana, S. boothii, S. lutea, *and* S. geyeriana) *seeds in Yellowstone National Park. Long-term grazing exclosures were used to compare seed production in unbrowsed versus browsed communities. The number of seeds per m² of female willow canopy coverage inside exclosures ranged from about 109,000 for* S. geyeriana *to over 583,000 for* S. lutea. *Outside the exclosures, no male or female aments (catkins) or willow seeds were produced. Individual willow plants with a few stems beyond the reach of ungulates on Yellowstone's northern range showed an identical pattern. Willow stems above the browse height (2.5 m) produced an abundance of male or female aments. No aments were produced on that portion of the plant exposed to browsing.*

INTRODUCTION

Numerous authors have demonstrated that ungulate browsing impairs the growth of trees and shrubs, which may lead to elimination of those species from their natural habitats (Putman and others 1989; Risenhoover and Maass 1987). In particular, elk (*Cervus elaphus*) can have a major impact on plant communities by reducing woody vegetation and promoting grasses through a combination of grazing and trampling (Edgerton 1987; Gysel 1960; Hanley and Taber 1980; Kay 1990; Tiedemann and Berndt 1972).

In response to this concern, wildlife biologists have conducted numerous clipping experiments to determine "proper use" levels for many shrubs because those plants are often key foods for big game during critical winter periods (Aldous 1952; Julander 1937; Krefting and others 1966; Lay 1965). In general, they found that most shrubs, including willows, increase vegetative production under light to moderate clipping. Based on these experiments and field observations, ungulate browsing is thought to stimulate aboveground shrub production. This has been seen as a positive

influence by most game managers, who often overlook long-term community relationships.

However, a few researchers have cautioned that browsing may depress seed production and thereby negatively impact plant populations over several generations (Verkaar 1987). Clipping suppressed flowering in many common browse species, and most plants produced flowers only on their upper, unclipped branches (Garrison 1953). Simulated winter browsing reduced female ament production in birch (*Betula pendula* and *B. pubescens*) (Bergstrom and Danell 1987), as well as seed production in rabbitbrush (*Chrysothamnus viscidiflorus*) and snowberry (*Symphoricarpos oreophilus*) (Willard and McKell 1978). Hemmer (1975) noted that browsing reduced berry production in serviceberry (*Amelanchier alnifolia*). Shepherd (1971) observed that heavy clipping reduced fruit production in serviceberry, mountain-mahogany (*Cercocarpus montanus*), Gambel oak (*Quercus gambelii*), bitterbrush (*Purshia tridentata*), and big sagebrush (*Artemisia tridentata*).

Seed predation has been shown to influence the species composition of vegetation communities over a wide range of habitats (Andersen 1989; Cavers 1983; Janzen 1971; Louda 1983; Schupp 1988). Most seed predation studies have focused on insects, birds, or small mammals. Reports of ungulate seed predation are uncommon, and few have investigated seed predation by large native ungulates in the Western United States.

This paper explores the impact native ungulates—elk, moose (*Alces alces*), mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), bighorn sheep (*Ovis canadensis*), and bison (*Bison bison*)—in Yellowstone National Park are having on the sexual reproduction of willows. Long-term grazing exclosures were used to compare seed production in unbrowsed versus browsed willow communities.

STUDY AREAS

Study sites were located on the winter range of the northern Yellowstone elk herd. Elk, the primary large herbivore, comprise approximately 80 percent of the total number of ungulates in the Greater Yellowstone Ecosystem (Kay 1990). Houston (1982) provides a description of the climate, physiography, and vegetation of Yellowstone's northern range. Location, date of establishment, and size of the exclosures used in this study have been summarized by Kay (1990). Barmore (1981: 453-459), Houston (1982: 415-420), and Chadde and Kay (1991) provide additional information on exclosures in Yellowstone National Park.

METHODS

The National Park Service established one permanent willow belt transect inside and another outside the Mammoth (1957), Junction Butte (1962), and Lamar-East (1957) exclosures at the time of construction. At Lamar-West (1962), a willow transect was established only inside the exclosure. The Lamar-East outside willow belt was intended as a control for both the Lamar-East and Lamar-West exclosures. Thus, seven permanent willow belt transects are associated with these exclosures; three outside and four inside. The belt transects at Mammoth, Lamar-East, and Lamar-West are all 1.5 by 30.5 m; those at Junction Butte are 1.5 by 22.9 m. Data on willow canopy coverage and plant height have been collected by the Park Service at various intervals since these exclosures were established. That information, repeat photographs of the belt transects, and additional data collected during 1988 were summarized by Kay (1990) and Chadde and Kay (1991).

Willow Aments

Because there were so few willow aments in areas exposed to repeated ungulate browsing, we recorded the number of aments on the entire belt transect outside each exclosure. In addition, we searched large areas of willow habitat (Chadde and others 1988) adjacent to each exclosure for willow aments and recorded those numbers. However, these procedures were impractical inside the exclosures due to the much greater ament densities that we encountered. Instead, inside the exclosures we counted aments on 1-m² plots placed in willow canopies.

Whenever possible, we sampled willows on the inside belt transects, but in most instances we also measured some plants adjacent to the permanent belt transects to obtain an adequate sample. All willows inside the exclosures produced aments, but it was easier to count aments on plants that were in full flower at the time of our visit. Furthermore, our equipment (a 2.5-m stepladder) prevented us from sampling plants taller than 3.5 m. We recorded the sex of all willows on and adjacent to the permanent belt transects. Willows were sampled during spring 1989.

We sampled only the major willow species within exclosures (Chadde and Kay 1991). These included *S. bebbiana*, *S. boothii*, *S. lutea*, and *S. geyeriana* for which we collected samples of female aments from each exclosure. We counted the mature fruits on 60 female aments of each species from each exclosure. Those aments were then air dried in the laboratory and the number of seeds in 10 fruits counted for each species-exclosure. We were unable to make identical measurements on female aments outside exclosures, because ament production was nonexistent there.

As part of another study, Chadde and others (1988) constructed two small exclosures (2 by 4 m) in 1986 adjacent to and sharing a common side with each of the Mammoth and Junction Butte exclosures. A trench 0.5 m deep was dug along the common side and a plastic barrier installed to sever root connections with plants in the older exclosure. Willow stems <30 cm tall were present inside each mini-exclosure when they were erected. We recorded all the aments inside four of these mini-exclosures in 1989 after three seasons of protection from browsing.

Individual Plants

Though rare, some willows and other shrubs on the northern range have branches that are beyond the reach of elk (Kay 1990). On those plants, a few tall, central stems are usually surrounded by a large number of lower, repeatedly browsed stems. Several of these "mushroom" willows exist near Geode Creek. To evaluate the effect of browsing on ament production of individual willows, we recorded the number of male or female aments on all stems above and below the browse height (2.5 m) on each plant. We gathered similar data on river birch (*Betula occidentalis*) near the Mammoth exclosure. These measurements were taken in 1989.

RESULTS

As reported in a previous paper (Chadde and Kay 1991), willows were taller and had greater canopy coverage inside than outside each exclosure. Other less palatable shrubs, such as rose (*Rosa woodsii*) and river birch, exhibited this same pattern. When pooled, these differences were statistically significant across exclosures ($p < 0.01$). Outside these exclosures, the mean height of all willow species was 34 cm while inside it was 274 cm ($p < 0.01$). When the non-willow portions of the belt transects were excluded, willow canopy coverage averaged 14 percent outside the exclosures and 95 percent inside ($p < 0.01$). Thus, willow canopy closure was nearly complete inside the exclosures.

Outside the exclosures, no aments were present in any of the permanent willow belt transects (table 1). Furthermore, only eight male aments were found in an additional 1.13 ha of willow-dominated habitat that we searched adjacent to the four exclosures on Yellowstone's northern range. In contrast, *S. bebbiana*, *S. boothii*, *S. lutea*, and *S. geyeriana* produced an average, respectively, of 1,445, 583, 694, and 1,346 female aments per m² of canopy coverage inside exclosures (table 2).

Table 1—Number of aments produced by willows in permanent belt transects and adjacent areas outside Yellowstone exclosures

| Exclosure | Permanent belt transects | | Adjacent areas | |
	Size	Number of aments	Size	Number of aments
	m²		m²	
Mammoth[1]	46.5	0	3,000	0
Junction Butte	34.8	0	800	0
Lamar-West	(²)	(²)	3,500	0
Lamar-East	46.5	0	4,500	[3]8
Mean number of aments per m²		0		0.0007

[1]There were also no male or female aments on *Betula occidentalis* plants in this belt transect.
[2]There is no permanent willow belt transect outside this exclosure (see text).
[3]Male *Salix bebbiana* protected from browsing by dead stems.

Table 2—Mean number of aments, fruits, and seeds produced by willows inside Yellowstone exclosures

Species-exclosure	Mean (SEM) aments per m² of canopy coverage		Mean (SEM) matured fruit per female ament ($n = 60$)	Mean (SEM) seeds per fruit ($n = 10$)	Mean number of seeds per m² of canopy coverage
	Male	Female			
Salix bebbiana					
Mammoth	1,878 (102)	1,006 (320)	31.6 (1.2)	5.1 (0.2)	162,127
Junction Butte	1,219 (539)	1,631 (594)	23.7 (1.2)	6.1 (0.4)	235,794
Lamar-West	4,083 (827)	1,482 (216)	46.5 (1.5)	5.8 (0.5)	399,695
Lamar-East	3,080 (0)	1,660 (213)	47.8 (1.4)	6.5 (0.3)	515,854
Subtotals	2,565 (636)	1,445 (151)	37.4 (5.9)	5.9 (0.3)	318,854
Salix boothii					
Mammoth	— —	382 (0)	43.4 (2.0)	6.6 (0.3)	109,420
Lamar-West	1,860 (0)	447 (184)	79.0 (2.0)	6.0 (0.3)	211,878
Lamar-East	— —	920 (0)	71.2 (1.2)	6.0 (0.4)	393,024
Subtotals	1,860 (0)	583 (170)	64.5 (10.8)	6.2 (0.2)	233,142
Salix lutea					
Mammoth	— —	490 (0)	78.4 (2.8)	11.8 (0.4)	453,309
Junction Butte	1,340 (0)	612 (130)	— —	— —	—
Lamar-West	— —	980 (0)	69.2 (3.4)	10.9 (0.6)	739,194
Subtotals	1,340 (0)	694 (147)	73.8 (4.6)	11.4 (0.4)	583,876
Salix geyeriana					
Mammoth	— —	931 (0)	13.0 (0.4)	4.7 (0.3)	56,884
Junction Butte	— —	— —	11.8 (0.5)	3.6 (0.2)	—
Lamar-West	4,300 (0)	1,846 (666)	29.0 (0.9)	5.9 (0.4)	315,850
Lamar-East	3,560 (0)	1,260 (502)	16.4 (0.6)	4.4 (0.3)	90,922
Subtotals	3,930 (370)	1,346 (267)	17.6 (3.9)	4.6 (0.5)	108,972
Total	[1]2,665 (620)	[1]1,001 (241)			306,988

[1]$t = 3.98$, $p < 0.01$.

For all willow species sampled inside exclosures, male aments were 2.7 times more abundant per m² of canopy coverage than female aments. The number of seeds per m² of female willow canopy coverage ranged from a low of about 109,000 for *S. geyeriana* to over 583,000 for *S. lutea* and averaged nearly 307,000. Since no female aments were found outside the exclosures, obviously no seeds could have been produced.

Female willow plants were more common than male plants inside the exclosures and, on average, outnumbered males 1.7 to 1 (table 3). When the mean sex ratio is combined with species canopy coverage (Chadde and Kay 1991) and species seed production values (table 2), an estimate of the total number of seeds produced in the inside and outside willow belt transects can be calculated. Approximately 5,857,000 seeds were produced in the willow transect inside the Junction Butte exclosure and zero outside; Lamar-East had 6,961,000 seeds inside, zero outside; Lamar-West 7,016,000 seeds inside, zero outside; and Mammoth 3,177,000 seeds inside, zero outside.

Individual plants with a few stems beyond the reach of ungulates on Yellowstone's northern range showed an identical pattern. Willow stems above the browse height (2.5 m) produced an abundance of male or female aments; no aments were produced on that portion of the plant exposed to browsing (table 4). Individual river birch (table 5) plants exhibited a similar pattern.

Table 3—Sex of willow plants inside Yellowstone exclosures

Exclosure-species	Number of plants		Ratio male to female
	Male	Female	
Mammoth			
S. bebbiana	6	4	
S. geyeriana	0	1	
S. boothii	0	2	
Subtotals	6	7	1:1.2
Junction Butte			
S. bebbiana	6	10	
S. lutea	4	12	
S. geyeriana	2	0	
Subtotals	12	22	1:1.8
Lamar-East			
S. bebbiana	2	8	
S. geyeriana	3	6	
S. boothii	3	2	
Subtotals	8	16	1:2.0
Lamar-West			
S. bebbiana	10	9	
S. boothii	3	6	
S. geyeriana	0	1	
S. lutea	0	5	
Subtotals	13	21	1:1.6
Totals	39	66	1:1.7

Table 4—Number of aments produced above and below browse height (2.5 m) on individual willows in Yellowstone National Park near Geode Creek

Species-plant	Plant size canopy coverage	Number of stems above browse height	Number of aments per plant Below browse height	Number of aments per plant Above browse height
	m²			
Salix lutea				
A-female	12	5	0	1,680
B-female	2	1	0	78
C-female	2	2	0	170
D-male	3	9	0	1,140
Salix geyeriana				
E-female	4	2	0	160
F-female	1	3	0	1,351
G-female	3	5	0	600
Salix boothii				
H-female	2	2	0	182
Mean			[1]0	[1]670

[1]*t* = 2.80, *p* < 0.02.

Table 5—Number of aments produced above and below browse height (2.5 m) on individual river birch plants near Yellowstone's Mammoth exclosure

Plant	Plant size canopy coverage	Number of stems above browse height	Number of aments on plant Above browse height Female	Number of aments on plant Above browse height Male	Number of aments on plant Below browse height Female	Number of aments on plant Below browse height Male
	m²		*Female*	*Male*	*Female*	*Male*
A	4	1	16	280	0	[1]18
B	16	2	0	39	0	0
C	12	2	951	1,291	0	0
D	12	1	272	784	0	[1]3
Mean			310	598	0	5

[1]Protected from browsing by dead stems.

Willows protected for three growing seasons increased in height but produced less than two male or female aments per m² (table 6). It apparently will take several more years for those plants to reach their full reproductive potential.

DISCUSSION

Mechanisms Limiting Seed Production

Winter browsing limits willow seed production in at least three ways. First, browsing removes flower buds that developed the previous fall (Garrison 1953: 315-316; Jameson 1963; Mosseler and Papadopol 1989: 2569). When those plants begin growth the following spring, few flowering buds are present. Lateral buds often produce new leader growth, but they will not produce flowering buds that spring (Childers 1975: 128). Flowering buds are most commonly produced on the previous year's growth. If that woody material is consumed by ungulates, those plants cannot flower the following spring and seeds are not produced. From 1970 to 1978, ungulates on Yellowstone's northern range on average consumed over 91 percent of

the current year's willow stem growth (Houston 1982: 149). Willow utilization has not decreased in recent years (Kay 1990).

Second, as Harper (1977: chap. 21) noted, plants allocate resources between vegetal growth and reproduction. Plants that must allocate resources to herbivore-induced vegetative growth are unlikely to produce many seeds (Garrison 1953: 316; Hemmer 1975). Further, woody plants pass through a juvenile or vegetative phase during which they cannot be induced to flower (Krugman and others 1974; Zimmerman 1972). On Yellowstone's northern range, repeatedly browsed willows often exhibit juvenile characteristics (Despain 1989).

Finally, since there is a positive correlation between size of individual plants and size of the fruit crop (Herrera 1984: 390; Peters and others 1988), grazing-induced size limitation also reduces the number of seeds produced. These three mechanisms apparently operate to curtail seed production when plants are exposed to frequent ungulate browsing, as in Yellowstone.

Though we measured seed production only in 1 year, the pattern of virtually no seed production outside the

| Location/mini-exclosure | Number of aments per m² for total enclosed area | | | |
| | Salix bebbiana | | Salix lutea | |
	Female	Male	Female	Male
Mammoth				
M-North	0	1.0	0	0
M-South	0	0	2.8	.4
Junction Butte				
M-West	.5	0	1.4	2.9
M-East	0	1.1	.5	.2
Mean	.1	.5	1.2	.9

exclosures, but abundant seed production within, probably reflects what happens every year. Observations on willows at these exclosures in other years and at other exclosures not included in this study support this conclusion (Kay 1990).

Comparison With Other Studies

Katsma and Rusch (1980) reported that simulated winter deer browsing reduced apple production the following year. Ungulate browsing caused a 61 to 86 percent reproductive depression in *Rosa canina* (Herrera 1984). Allison (1987) concluded that winter browsing by white-tailed deer (*O. virginianus*) affected Canada yew (*Taxus canadensis*) sexual reproduction by reducing pollen production, which, in turn, caused seed production to decline. On Isle Royale, repeated browsing by moose prevented recruitment by balsam fir (*Abies balsamea*), and "no cone production was observed on any browse stunted sapling" (Brander and others 1990: 162).

To the best of our knowledge, no published studies have reported the level of ungulate-induced seed production loss we encountered. Even studies of small mammals, birds, and insects have seldom documented the level of seed loss observed in Yellowstone. For instance, Elmquist and others (1987) reported stem girdling by mice reduced willow seed production a maximum of 94 percent. However, in Yellowstone Park, ungulate browsing reduced potential willow seed production by 100 percent. Moreover, based on photographic evidence (Chadde and Kay 1991), few willows on Yellowstone's northern range appear to have produced seeds for the last 50 or so years.

"Natural Regulation"

The relationship between vegetation and ungulates in Yellowstone has long been a subject of conflicting opinions and intense debate (Chase 1986; Despain and others 1986; Houston 1982; Kay 1990). Prior to 1968, the Park Service contended that an "abnormally" large elk population, which had built up in Yellowstone during the late 1800's and early 1900's, had severely "damaged"[1] the park's northern

winter range, including willow communities. However, agency biologists now hypothesize that elk and other animals in Yellowstone are "naturally regulated," being resource (food) limited (Houston 1976, 1982; Kay 1990).

Park Service biologists now believe elk, vegetation, and other herbivores in Yellowstone have been in equilibrium for several thousand years (Despain and others 1986). They also believe that any changes in plant species composition or height are due primarily to suppression of lightning fires, normal plant succession, or climatic change, not ungulate grazing. Houston (1982: 129) concluded that "while ungulates and other herbivores affected the rate of primary succession, changes in distribution of willow were mostly climatically determined."

Houston (1976) indicated that if willow communities had actually declined on the northern range because of ungulate browsing, this would be a basis for rejecting the "natural regulation" hypothesis. Because "natural regulation" is a global equilibrium model, grazing-induced changes in vegetation height since 1872, when the park was created, would also indicate the herbivores have not been in equilibrium with their food resources. Therefore, if ungulate browsing on the northern range has changed what were once tall willow communities into short willow types, this would be additional grounds for rejecting "natural regulation."

Based on 48 repeat photosets of willow communities in the park, some dating from 1871, historical accounts, and other data, Chadde and Kay (1991) concluded that Yellowstone's tall willows had declined approximately 95 percent since the park was established, not because of climatic change or succession, but primarily from repeated ungulate browsing. We suggest that the virtual elimination of willow seed production also indicates Yellowstone's ungulates and vegetation are not in equilibrium. Once the existing willows die of old age, disease, insects, or other causes, they cannot be replaced by new plants produced from seed. Under these conditions, willows will eventually disappear. Willows commonly colonize new habitats by producing vast numbers of wind-dispersed seeds. Yet, during a 3-year study to classify wetland communities on the northern range, Chadde and others (1988) observed few willow seedlings on newly created gravel bars and mud flats, which normally provide ideal seed beds.

Several researchers have questioned the importance of seed predation to recruitment in stable populations of

[1]Terms such as "over grazing," "range damage," and "unnatural" elk populations are common in nearly all early, government reports on the elk herds in the Greater Yellowstone Ecosystem. Since these terms are value-laden, they are used here only in their historical context.

long-lived perennials (Duggan 1985). Anderson (1989) concluded that, "The importance of seed losses to population recruitment at any point in time is related to the abundance of safe sites [for seed germination and seedling establishment]...it is zero when safe sites are absent, negligible when safe sites are rare, and greatest when safe sites are numerous enough for recruitment to be limited by seed supply." He noted that soil seed banks could offset any long-term impacts of seed predation to long-lived perennials.

However, since willow seeds are short lived and are not stored in soil seed banks (Brinkman 1974; Densmore and Zasada 1983), this cannot be an important consideration in willow ecology. Moreover, even if willow seedlings become established outside the exclosures, the level of ungulate browsing that exists would prevent those plants from being recruited into their sexually reproducing populations.

For instance, the few large cottonwoods (*Populus trichocarpa* and *P. angustifolia*) remaining along waterways in Yellowstone Park produce abundant seeds, some of which establish on gravel bars along rivers and streams. However, almost none of those plants has been successfully recruited into their sexually reproducing populations over the last 80 or so years, because repeated ungulate browsing has prevented new cottonwoods from growing taller than 1 m (Chadde and others 1988; Kay 1990). Chadde and Kay (1991) reported that willows established from seed on a gravel bar along Yellowstone's Gardiner River were replaced by grasses and other herbaceous plants within 9 years due to repeated ungulate browsing. During the mid-1970's, a few tall willows were still alive above and below this gravel bar. Those plants probably produced the seeds that became established on this gravel bar. Since that time, continued ungulate browsing in combination with insects and pathogens has eliminated those tall willows (Kay 1990).

Without abundant seed crops, willows cannot take advantage of recruitment opportunities produced by periodic large-scale disturbances such as fire. Yellowstone's 1988 fires occurred under extreme burning conditions during an extended drought and are thought to have been a 100-300-year event (Romme and Despain 1989a, 1989b). Hence, those fires were able to burn normally wet riparian zones (Knight and Wallace 1989), many of which had thick sedge (*Carex* spp.) mats and accumulations of organic matter (Brichta 1987; Chadde and others 1988). These areas, normally unfavorable to willow seed germination and seedling establishment, "were burned down to mineral soil, killing rhizomes and root systems" (Knight and Wallace 1989: 704). This created bare mineral soil and ash substrates that had abundant soil moisture especially after snowmelt in 1989—ideal conditions for germination and seedling establishment of willow (Brinkman 1974). Yet, few willow seedlings were observed in those areas (Kay 1990). Our data indicate that practically no willow seeds were produced on Yellowstone's northern range to colonize this newly created habitat.

Agency biologists, with little supporting evidence, have assumed that 12,000-15,000 elk wintered on the northern range over the last several thousand years (Despain and others 1986; Houston 1982). However, some measure of pre-European ungulate populations and relative species abundance is needed to determine the level of grazing pressure under which willows have persisted in the Yellowstone area. Based on extensive archaeological research in northwest Wyoming, Wright (1984) concluded that large herds of elk did not inhabit the Greater Yellowstone Ecosystem until the late 1800's. In fact, all the available archaeological evidence suggests that elk were not common in the Yellowstone area over the last several thousand years (Eakin 1986; Eakin and others 1986; Frison 1978; Frison and Walker 1984; Harris 1978; Hoefer 1986; Lahren 1976; Walker 1987). Of ungulate bones unearthed from Yellowstone archaeological sites, elk made up less than 3 percent of the total and elk only accounted for 3 percent of over 52,000 ungulate bones identified from more than 200 archaeological sites throughout the Intermountain West (Kay 1990).

Furthermore, woody plants (including willows) depicted in early (1870-90) Yellowstone photographs show absolutely no evidence of ungulate browsing (Kay 1990). This may explain how willows in Yellowstone were able to maintain viable populations over the past millennia. These data also suggest that some factor besides resource competition was the primary determinant of ungulate abundance and distribution prior to European influence.

Applicability to Other Areas

Though we only measured the impact that native ungulates, primarily elk, have had on willow seed production in Yellowstone National Park, domestic livestock could have a similar effect on willow communities throughout the West. If all the willows are within reach of domestic livestock and if those animals remove a large proportion of the plant's current annual growth, it is highly probable that willow seed production would also show a marked decline under those circumstances.

Browsing impacts on seed production should not be overlooked by managers who are working to restore disturbed riparian areas, especially ones which were degraded by excessive livestock grazing.

REFERENCES

Aldous, S. E. 1952. Deer browse clipping study in the Lake States region. Journal of Wildlife Management. 16: 401-409.

Allison, T. D. 1987. The reproductive biology of Canada yew (*Taxus canadensis*) and its modification by herbivory: implications for wind pollination. Minneapolis, MN: University of Minnesota. Dissertation.

Anderson, A. N. 1989. How important is seed predation to recruitment in stable populations of long-lived perennials? Oecologia (Berlin). 81: 310-315.

Barmore, W. J. 1981. Population characteristics, distribution, and habitat relationships of six ungulate species on winter range in Yellowstone National Park. Mammoth, WY: U.S. Department of the Interior, National Park Service, Yellowstone National Park, Research Office. 677 p. Unpublished report.

Bergstrom, R.; Danell, K. 1987. Effects of simulated winter browsing by moose on morphology and biomass of two birch species. Journal of Ecology. 75: 533-544.

Borchert, M. I.; Davis, F. W.; Michaelsen, J.; Oyler, L. D. 1989. Interactions of factors affecting seedling recruitment of blue oak (*Quercus douglasii*) in California. Ecology. 70: 389-404.

Brander, T. A.; Peterson, R. O.; Risenhoover, K. L. 1990. Balsam fir on Isle Royale: effects of moose herbivory and population density. Ecology. 71: 155-164.

Brichta, P. H. 1987. Environmental relationships among wetland community types on the northern range, Yellowstone National Park. Missoula, MT: University of Montana. 67 p. Thesis.

Brinkman, K. A. 1974. *Salix* L.—willow. In: Seeds of woody plants in the United States. Agric. Handb. 450. Washington, DC: U.S. Department of Agriculture, Forest Service: 746-750.

Cavers, P. B. 1983. Seed demography. Canadian Journal of Botany. 61: 3578-3590.

Chadde, S. W.; Kay, C. E. 1991. Tall willow communities on Yellowstone's northern range: a test of the "natural regulation" paradigm. In: Keiter, R.; Boyce, M., eds. The greater Yellowstone ecosystem: balancing man and nature on America's wildlands. New Haven, CT: Yale University Press: 231-262.

Chadde, S. W.; Hansen, P. L.; Pfister, R. D. 1988. Wetland plant communities on the northern range of Yellowstone National Park. Final contract report to National Park Service, Yellowstone National Park. Missoula, MT: University of Montana, School of Forestry. 81 p.

Chase, A. 1986. Playing God in Yellowstone: The destruction of America's first National Park. Boston: Atlantic Monthly Press. 446 p.

Childers, N. F. 1975. Modern fruit science. 6th ed. New Brunswick, NJ: Rutgers University, Horticultural Publications. 976 p.

Densmore, R.; Zasada, J. 1983. Seed dispersal and dormancy patterns in northern willows: ecological and evolutionary significance. Canadian Journal of Botany. 61: 3201-3216.

Despain, D. G. 1989. Interpretation of exclosures in riparian vegetation. In: Gresswell, R. E.; Barton, B. A.; Kershner, J. L., eds. Practical approaches to riparian management: an educational workshop. Rep. BLM-MT-PT-89-001-4351. Billings, MT: U.S. Department of the Interior, Bureau of Land Management, Montana State Office: 188.

Despain, D.; Houston, D.; Meagher, M.; Schullery, P. 1986. Wildlife in transition: man and nature on Yellowstone's northern range. Boulder, CO: Roberts Rinehart. 142 p.

Duggan, A. E. 1985. Pre-dispersal seed predation by *Anthocaris cardamines* (Pieridae) in the population dynamics of the perennial *Cardamine pratensis* (Brassicaceae). Oikos. 44: 99-106.

Eakin, D. H. 1986. Results of additional archaeological investigations along sections of the North Fork of the Shoshone River, Highway 14, 16, 20. Highway project SCPF-031-1 (21). Project No. WY-49-84. Laramie, WY: Office of Wyoming State Archaeologist. 58 p. + appendix.

Eakin, D. H.; Darlington, D.; Peyton, L. 1986. Results of archaeological investigations along sections of the North Fork of the Shoshone River, Highway 14, 16, 20. Highway project SCPF-031-1 (21). Project No. WY-49-84. Laramie, WY: Office of Wyoming State Archaeologist. 135 p.

Edgerton, P. J. 1987. Influence of ungulates on the development of the shrub understory of an upper slope mixed conifer forest. In: Provenza, Frederick D.; Flinders, Jerran T.; McArthur, E. Durant, compilers. Proceedings—symposium on plant-herbivore interactions; 1985 August 7-9; Snowbird, UT. Gen. Tech. Rep. INT-222. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 162-167.

Elmquist, T.; Ericson, L.; Danell, K.; Salomonson, A. 1987. Flowering, shoot production, and vole bark herbivory in boreal willow. Ecology. 68: 1623-1629.

Frison, G. C. 1978. Prehistoric hunters of the high plains. New York: Academic Press. 457 p.

Frison, G.; Walker, D. N., eds. 1984. The Dead Indian Creek site: an archaic occupation in the Absaroka Mountains of northeastern Wyoming. Wyoming Archaeologist. 27(1-2): 11-122.

Garrison, G. A. 1953. Effects of clipping on some range shrubs. Journal of Range Management. 6: 309-317.

Gysel, L. W. 1960. An ecological study of the winter range of elk and mule deer in the Rocky Mountain National Park. Journal of Forestry. 58: 696-703.

Hanley, T. A.; Taber, R. D. 1980. Selective plant species inhibition by elk and deer in three conifer communities in western Washington. Forest Science. 26: 97-107.

Harper, J. L. 1977. Population biology of plants. New York: Academic Press. 456 p.

Harris, A. 1978. The Mummy Cave tetropods. In: McCracken, H., ed. The Mummy Cave project in Northwestern Wyoming. Cody, WY: Buffalo Bill Historical Center: 146-151.

Hemmer, D. 1975. Serviceberry: ecology, distribution, and relationships to big game. Project W-120-R-5 and 6. Helena, MT: Montana Fish and Game Department; Job Completion Report. 76 p.

Herrera, C. M. 1984. Seed dispersal and fitness determinants in wild rose: combined effects of hawthorn, birds, mice and browsing ungulates. Oecologia (Berlin). 63: 386-393.

Hoefer, T. 1986. Archaeological data recovery at site 48 SW 1242: La Barge natural gas project. Cultural Resour. Manage. Rep. 21. Rock Springs, WY: Western Wyoming College, Archaeological Services.

Houston, D. B. 1976. Research on ungulates in northern Yellowstone National Park. In: Research in the parks: Transactions of the National Park Centennial Symposium; 1971 December; National Park Service Symposium Series No. 1. Washington, DC: U.S. Department of the Interior, National Park Service: 11-27.

Houston, D. B. 1982. The northern Yellowstone elk: ecology and management. New York: MacMillan. 474 p.

Jameson, D. A. 1963. Responses of individual plants to harvesting. Botanical Review. 29: 532-594.

Janzen, D. H. 1971. Seed predation by animals. Annual Review of Ecology and Systematics. 2: 465-492.

Julander, O. 1937. Utilization of browse by wildlife. Transactions of the North American Wildlife Conference. 2: 276-287.

Katsma, D. E.; Rusch, D. H. 1980. Effects of simulated deer browsing on branches of apple trees. Journal of Wildlife Management. 44: 603-612.

Kay, C. E. 1990. Yellowstone's northern elk herd: a critical evaluation of the "natural regulation" paradigm. Logan, UT: Utah State University. 490 p. Dissertation.

Knight, D. H.; Wallace, L. L. 1989. The Yellowstone fires: issues in landscape ecology. BioScience. 39: 700-706.

Krefting, L. W.; Stenlund, M. H.; Seemel, R. K. 1966. Effect of simulated and natural browsing on mountain maple. Journal of Wildlife Management. 30: 481-488.

Krugman, S. L.; Stein, W. I.; Schmitt, D. M. 1974. Seed biology. In: Seeds of woody plants of the United States. Agric. Handb. 450. Washington, DC: U.S. Department of Agriculture, Forest Service: Chapter 1.

Lahren, L. A. 1976. The Myers-Hindman site: an exploratory study of human occupation patterns in the upper Yellowstone Valley from 7000 BC to AD 1200. Livingston, MT: Anthropologos Researches International. 195 p.

Lay, D. W. 1965. Effects of periodic clipping on yield of some common browse species. Journal of Range Management. 18: 181-184.

Louda, S. M. 1983. Seed predation and seedling mortality in the recruitment of a shrub, *Haplopappus venetus* (Asteraceae), along a climatic gradient. Ecology. 64: 511-521.

Mosseler, A.; Papadopol, C. S. 1989. Seasonal isolation as a reproductive barrier among sympatric *Salix* species. Canadian Journal of Botany. 67: 2563-2570.

Peters, R. H.; Cloutier, S.; Dube, D.; Evans, A.; Hastings, P.; Kaiser, H.; Kohn, D.; Sarwer-Foner, B. 1988. The allometry of the weight of fruit on trees and shrubs in Barbados. Oecologia (Berlin). 74: 612-616.

Putman, R. J.; Edwards, P. J.; Mann, J. C. E.; How, R. C.; Hill, S. D. 1989. Vegetational and faunal changes in an area of heavily grazed woodland following relief of grazing. Biological Conservation. 47: 13-32.

Risenhoover, K. L.; Maass, S. A. 1987. The influence of moose on the composition and structure of Isle Royale forests. Canadian Journal of Forest Research. 17: 357-364.

Romme, W. H.; Despain, D. G. 1989a. Historical perspective on the Yellowstone fires of 1988. BioScience. 39: 695-699.

Romme, W. H.; Despain, D. G. 1989b. The Yellowstone fires. Scientific American. 261(5): 37-46.

Schupp, E. W. 1988. Seed and early seedling predation in the forest understory and in treefall gaps. Oikos. 51: 71-78.

Shepherd, H. R. 1971. Effects of clipping on key browse species in southwestern Colorado. Tech. Publ. 28. Denver, CO: Colorado Division of Game, Fish and Parks. 104 p.

Tiedemann, A. R.; Berndt, H. W. 1972. Vegetation and soils of a 30-year deer and elk exclosure in central Washington. Northwest Science. 46: 59-66.

Verkaar, H. J. 1987. Population dynamics—the influence of herbivory. New Phytologist. 106(Suppl): 49-60.

Walker, D. N. 1987. Late Pleistocene/Holocene environmental changes in Wyoming: the mammalian record. In: Graham, R. W.; Semken, H. A.; Graham, M. A., eds. Late quaternary mammalian biogeography and environments of the Great Plains and prairies. Illinois State Museum Scientific Papers Vol. 22. Springfield, IL: Illinois State Museum: 334-393.

Willard, E. E.; McKell, C. M. 1978. Response of shrubs to simulated browsing. Journal of Wildlife Management. 42: 514-519.

Wright, G. A. 1984. People of the high country: Jackson Hole before the settlers. New York: Peter Lang. 181 p.

Zimmerman, R. H. 1972. Juvenility and flowering in woody plants: review. Hortscience. 7: 447-455.

245

VEGETATION, BREEDING BIRD, AND SMALL MAMMAL BIOMASS IN TWO HIGH-ELEVATION SAGEBRUSH RIPARIAN HABITATS

Warren P. Clary
Dean E. Medin

ABSTRACT

Two riparian areas, one in Nevada (Deer Creek) and one in Idaho (Summit Creek), were compared on the basis of vegetation, breeding bird, and small mammal characteristics. The two study areas had, except for geomorphology, many similar environmental characteristics, yet the biological communities differed widely in many attributes. Plant physiognomy was strikingly different, and total plant biomass differed by 25-fold. There was no overlap of riparian breeding bird species between areas. Various breeding bird and small mammal population measures differed between the two areas in their response to grazing. Overall, the natural variation between the two areas far exceeded the variation introduced by the grazing of cattle.

INTRODUCTION

Concentrations of factors such as water, nutrients, sediments, and organic matter in riparian areas permit development of biotic communities that are more diverse and productive than those of the surrounding uplands (Hubbard 1977; Jahn 1978; Thomas and others 1979). These productive ecosystems exhibit an almost unending variety of differences associated with geomorphology, stream type, elevation, and climate as well as variability in response to management stress.

Livestock grazing in riparian ecosystems has been a recent management concern in the Western United States (Swanson 1988). Cattle prefer riparian areas for the quality and variety of forage, for easy accessibility, for shade, and for a generally reliable source of water (Gillen and others 1985; Martin 1979; Skovlin 1984). Several studies have reported adverse effects of cattle grazing on riparian vegetation, and recovery of vegetation when grazing is modified, reduced, or eliminated (Knopf and Cannon 1982; Platts and Raleigh 1984; Rickard and Cushing 1982; Skovlin 1984; Taylor 1986). These vegetation changes may in turn be reflected in small wildlife population changes (Kauffman and others 1982; Taylor 1986).

The objectives of this study were to (1) investigate similarities and dissimilarities of riparian areas otherwise alike in a number of environmental conditions, and (2) examine their response to grazing stress. We compared vegetation, breeding bird, and small mammal characteristics on two riparian areas, one in Nevada (Deer Creek) and one in Idaho (Summit Creek). Sampling was conducted on sites grazed by cattle and on comparable adjacent sites protected from grazing.

STUDY AREAS

The two study areas were similar in elevation (1,890 to 1,980 m), precipitation (~250 mm), ecological zone (sagebrush), and in an early or midsummer to late-summer grazing pattern. The most apparent environmental difference between the two sites was geomorphology.

Deer Creek

The Deer Creek (DC) site is located 55 km north of Wells, in northeastern Nevada. The small stream originates from springs and flows in a narrow, V-shaped canyon cut into mid-Tertiary rhyolitic rock. Soils are generally fine-textured, ranging from shallow on steep residual slopes to very deep on relatively level alluvial fans and floodplains (Platts and others 1988). The riparian areas seldom exceed 25 to 50 m in width.

The stream was closely bordered by clumped stands of aspen (*Populus tremuloides*), willow (*Salix* spp.), and other deciduous shrubs. The herbaceous component was dominated by Kentucky bluegrass (*Poa pratensis*), bluebunch wheatgrass (*Agropyron spicatum*), and sedges (*Carex* spp.). The gallerylike riparian area appeared as an island surrounded by an upland plant community dominated by big sagebrush (*Artemisia tridentata*). With the exception of the big sagebrush/upland type, community types within the Deer Creek study area were considered as components of a riparian complex (Winward and Padgett 1989) typified by aspen, willow, and Kentucky bluegrass.

Narrow floodplains with dead and downed aspen are common in the study area. These remnants of aspen communities were once flooded by beaver impoundments that drowned the trees.

The study was conducted within a large (40+ ha) cattle exclosure, fenced 11 years previously (trespass grazing

did occur on several occasions), and on an adjacent area selected on the basis of topographical and vegetational type similarities with the exclosed area. The construction of the exclosure across the narrow Deer Creek canyon served as a drift-fence reducing the cattle use of the grazed portion of the study area (upstream side of the exclosure), compared to previous years.

Summit Creek

The Summit Creek (SC) study area is 41 km north of Mackay in Custer County, ID. Summit Creek originates from springs and flows through a gently sloping, basinlike valley bounded on the east by the Lemhi Range and on the west by the Lost River Range. The mountain ranges are rugged and serrated, and chiefly composed of limestone, dolomite, quartzite, shale, and schist (Kirkham 1927). Microrelief in many parts of the riparian area is hummocky, with soils high in total salts (USDA SCS 1987). The riparian zone seldom exceeds 50 to 100 m in width.

For this study, we consolidated plant communities into three general community types: sagebrush (*Artemisia* spp.)/upland, mat muhly (*Muhlenbergia richardsonis*)/ hummock, and mesic herbaceous. The sagebrush/upland type occupies the gentle slopes and terraces adjoining the riparian zone. The dominant shrubs are low sagebrush (*Artemisia arbuscula*) and threetip sagebrush (*A. tripartita*), with occasional individuals of green rabbitbrush (*Chrysothamnus viscidiflorus*), gray horsebrush (*Tetradymia canescens*), and big sagebrush. The mat muhly/hummock and mesic herbaceous types were considered components of the riparian complex. The hummocky areas are dominated by herbaceous species, most notably mat muhly and thick-spiked wheat grass (*Agropyron dasystachyum*). The stream is closely bordered by mesic herbaceous communities of Kentucky bluegrass, beaked sedge (*Carex rostrata*), and Baltic rush (*Juncus balticus*).

The study of Summit Creek was conducted within a 122-ha exclosure, constructed 14 years earlier, and on a comparable adjacent riparian area grazed by cattle. Occasional trespass grazing has occurred in the fenced area.

METHODS

Two 600- by 150-m sites (9-ha), one in the exclosure and the other in the adjoining grazed area, were sampled for vegetation and other characteristics in August 1988 (DC) and 1989 (SC). For each of the grazed and ungrazed situations, the riparian complex contained 40 (SC) to 60 (DC) sample locations.

Vegetation

A 50- by 50-cm (0.25-m²) quadrat was located at each of the systematically positioned sample locations. Canopy cover (Daubenmire 1959) was ocularly estimated for the total of each plant lifeform (graminoid, forb, shrub) and recorded in percentage as the midpoint of one of eight cover classes (0-1, 1-5, 5-10, 10-25, 25-50, 50-75, 75-95, 95-100). Percentages of litter, rock, bare ground, and

lichen-moss were similarly estimated. The vegetative height (excluding flower and seedhead height) of each graminoid, forb, and shrub nearest the center of each quadrat was recorded.

Biomass of graminoids, forbs, and small shrubs was determined by clipping vegetation from ground level upward within a vertical projection from the 0.25-m² quadrats. Clipped materials were bagged, ovendried, and weighed. A 3- by 3-m (9-m²) plot, concentric to each 0.25-m² quadrat, was used to sample biomass of large shrubs. Basal diameter, maximum height, and species were recorded for each shrub stem rooted within the plot. For willow clumps, average stem diameter and average stem height were recorded instead of individual stems. Biomass of willows and other large shrubs was estimated by use of the equations of Brown (1976). Height and diameter at breast height (d.b.h.) were recorded for each tree stem rooted within 10- by 10-m (100-m²) plots concentric to each 0.25-m² quadrat. Biomass of aspen was estimated by the Chicken Creek equations of Bartos and Johnson (1978).

Breeding Birds

The sites were censused for breeding birds using the spot-map method (International Bird Census Committee 1970). The census grids were oriented lengthwise along the creek and straddled the stream channel on both the grazed and ungrazed sites. Grid points were surveyed and marked with numbered stakes at 25-m intervals.

One observer (DEM) made 11 (SC) and 13 (DC) census visits to each site from mid-May to mid-June 1988 (DC) and 1989 (SC). Most of the spot-mapping was done from sunrise to early afternoon when birds were most active. To ensure complete coverage, he censused a site by walking within 25 m of all points on the grid. Census routes were varied. Recorded bird observations extended a minimum of 50 m beyond grid boundaries.

At the end of the sampling period, clusters of observations and coded activity patterns on species maps were circled as indicating areas of activity or approximated territories. Fractional parts of boundary territories were included. Oelke (1981) summarized methodological difficulties and other special problems of the mapping method. We followed Hill (1973) for estimates of bird species diversity. Wide-ranging raptorial birds, although commonly seen, were not included in the analysis. Transient species were also excluded.

Small Mammals

A 1.7-ha trapping grid was located in each of the grazed and ungrazed sites to estimate small mammal populations in midsummer 1988 (DC and SC) and 1989 (SC). Trapping grids were placed near the center of the 9-ha areas established to census bird populations. Each grid measured 225 by 75 m and consisted of 40 trapping stations systematically spaced at 25-m intervals in 10 rows and four columns.

The rectangular grids were positioned lengthwise along the stream and straddled the stream channel. Two

Museum Special mouse traps and one Victor rat trap were placed near each trapping station. Traps were baited with a mixture of peanut butter and rolled oats and examined daily for 5 consecutive days.

RESULTS AND DISCUSSION

We look at four topics in our study results: herbaceous and shrub vegetation; aspen; breeding birds; and small mammals.

Herbaceous and Shrub Vegetation

Deer Creek—There were not many structural differences in vegetation between the grazed and ungrazed areas at Deer Creek (tables 1 and 2). The most evident difference was in the herbaceous layer where graminoid biomass and graminoid and forb height values were reduced on the grazed site. Graminoid biomass, for example, on the grazed plot was only about half that inside the exclosure. The differences in grass biomass and heights seemed predominantly due to recent livestock grazing rather than to a basic difference in plant growth between the two areas. Forbs exhibited less difference in standing crop biomass and vegetative plant height than did the graminoids.

There were no significant differences in characteristics of small shrubs such as sagebrush between the grazed and fenced areas. There was, however, a large difference between the calculated means of the willow standing crop biomass, but the significance was masked by the extreme variation among samples. The biomass attributed to

large shrubs other than willow (currant [*Ribes* spp.], rose [*Rosa* spp.], snowberry [*Symphoricarpos* spp.], and so forth) was significantly higher in the grazed situation. Although one cannot be sure whether this is a response to site or grazing differences, Elmore (1988) described currant replacing willow and alder (*Alnus* spp.) when water tables were lowered in response to grazing or other stresses on the stream channel. Presumably, the reverse may also be true, so that if water tables rise in response to reduced erosion stress and to narrowing of the stream channels, willows may replace currant or rose or other plants.

There was little difference in the number of species per plot between grazed and ungrazed situations; thus grazing has not measurably affected overall plant diversities. Nevertheless, the grazed herbaceous plant compositions appeared to contain more Kentucky bluegrass than plant compositions in the fenced area. Ground cover characteristics were similar between the two areas, except for slightly more bare soil where grazing had occurred.

Summit Creek—There were no woody species within the riparian complex of the study area (tables 1 and 2). The most evident structural difference in the vegetation was in height values. Graminoid and forb heights were significantly reduced on the grazed site as were graminoid and forb biomass and graminoid canopy cover. Graminoid biomass on the grazed plot was only about one-eighth that inside the exclosure.

There was more bare soil, rock, and lichen-moss cover on the grazed area (table 2). A small but significant increase in plant species occurred on the ungrazed area. A grazing-induced shift toward Kentucky bluegrass from sedges was apparent on the wet streamside areas.

Table 1—Herbage and shrub biomass

Plant group	Biomass (g/m²)													
	Ungrazed						Grazed						P (totals)[1]	
	Live		Dead		Total		Live		Dead		Total			
	DC	SC	DC	SC	DC	SC	DC	SC	DC	SC	DC	SC	DC	SC
Grass	131.3	245.9	65.1	136.8	196.4	382.7	74.5	46.7	23.7	0	98.2	46.7	[2]<0.01	<0.01
Forb	16.5	33.3	.1	—	16.6	33.3	13.3	14.7	0	0	13.3	14.7	.20	<.01
Total herbage	147.8	279.2	65.2	136.8	213.0	416.0	87.7	61.4	23.7	0	111.5	61.4	<.01	<.01
Small shrub														
Foliage	13.8	—	—	—	13.8	—	18.6	—	—	—	18.6	—	.44	—
Wood	23.4	—	3.1	—	26.5	—	24.8	—	11.7	—	36.5	—	.43	—
Total	37.2	—	3.1	—	40.3	—	43.4	—	11.7	—	55.1	—	.42	—
Large shrub														
Willow														
Foliage	73.9	—	—	—	73.9	—	63.3	—	—	—	63.3	—	.74	—
Wood	1,810.9	—	5.6	—	1,816.5	—	646.8	—	9.8	—	656.6	—	.41	—
Total	1,884.8	—	5.6	—	1,890.4	—	710.1	—	9.8	—	719.9	—	.41	—
Nonwillow														
Foliage	6.2	—	—	—	6.2	—	128.1	—	—	—	128.1	—	.01	—
Wood	8.3	—	13.8	—	22.1	—	440.3	—	10.0	—	450.3	—	.06	—
Total	14.5	—	13.8	—	28.3	—	568.4	—	10.0	—	578.4	—	.04	—

[1]n = 60 on Deer Creek, 40 on Summit Creek.
[2]Probability associated with unpaired t-tests. Probabilities less than 0.10 suggest a significant difference between grazed and ungrazed areas.

Table 2—Ground cover and miscellaneous characteristics

Item	Ungrazed		Grazed		P[1]	
	DC	SC	DC	SC	DC	SC
Cover (percent)						
Bare	5.6	6.6	9.6	15.2	[2]0.08	0.03
Litter	29.5	5.8	25.2	5.7	.20	.94
Rock	2.1	.1	4.0	.6	.22	.04
Lichen-moss	<.1	.1	.1	1.0	.58	.02
Grass	56.0	77.4	54.7	67.4	.72	.06
Forb	7.6	16.3	6.6	14.2	.54	.47
Shrub	4.2	0	5.2	0	.59	—
Plant height (m)						
Grass	.37	.22	.25	.05	<.01	<.01
Forb	.16	.08	.12	.03	.06	<.01
Shrub	1.35	—	1.46	—	.61	—
Species per 0.25 m²						
Grass	2.28	3.82	2.40	3.22	.30	.02
Forb	1.60	2.95	1.37	2.55	.24	.19
Shrub	.33	0	.43	0	.36	—

[1]$n = 60$ on Deer Creek, 40 on Summit Creek.
[2]Probability associated with unpaired t-tests. Probabilities less than 0.10 suggest a significant difference between grazed and ungrazed areas.
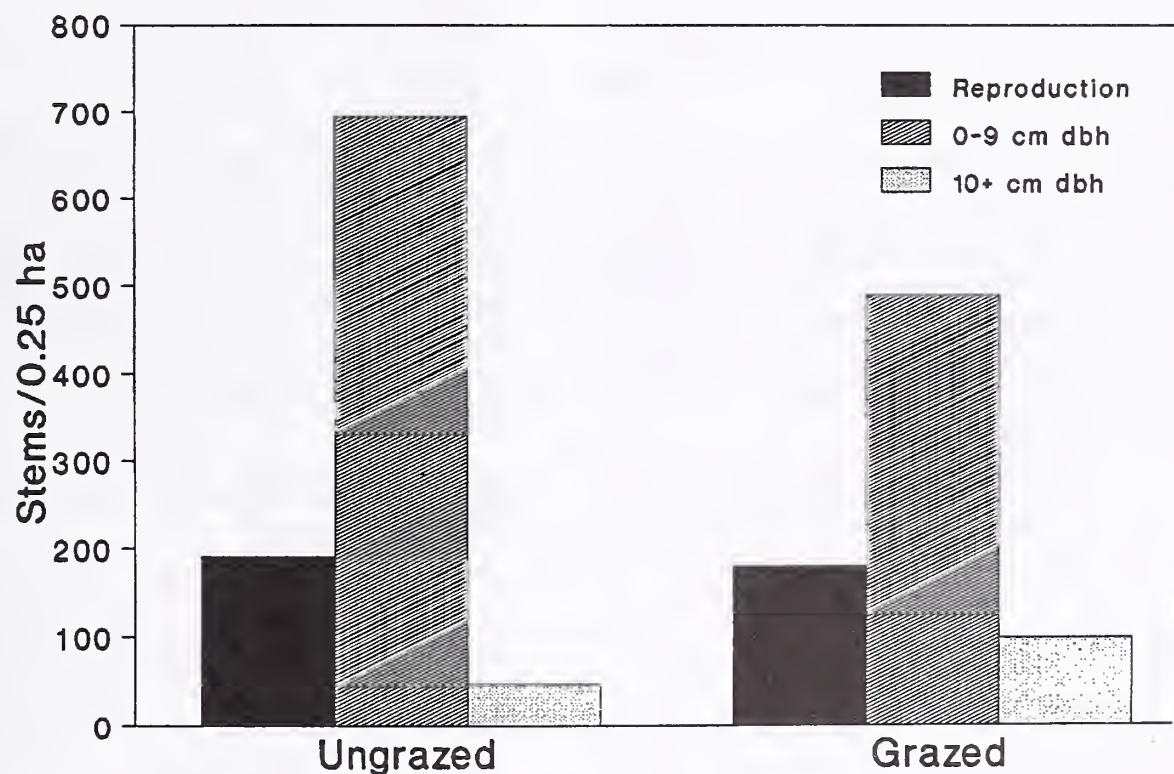
Figure 1—Size class distribution of aspen stems within Deer Creek aspen stands.

Aspen

Deer Creek—Although a grazing management change of only 11 years at Deer Creek would not likely affect a stand of large, mature aspen trees, it apparently caused a change in the young age classes of aspen. A very heavily grazed area adjacent to the Deer Creek site plots had no sapling-sized trees. However, both the grazed site and the ungrazed site had substantial numbers of sapling-sized aspen (up to 9 cm d.b.h. and about 6.5 m tall), the largest of which were dated by tree-ring counts to the year of fence construction (fig. 1).

Removal of grazing normally results in an increase in aspen reproduction (DeByle 1985). However, the moderation of grazing on the grazed study site, due to the barrier effect of the exclosure fence in the narrow canyon, appears to have also resulted in an increase in aspen reproduction, although in somewhat reduced numbers compared to the

exclosure. These saplings should provide a basis for continuation of the aspen stand after the current mature trees senesce. The total lack of the sapling size class in the nearby very heavily grazed area foretells the eventual loss of this aspen stand under current grazing practices.

Summit Creek—There were no trees on the Summit Creek study area.

Birds

Deer Creek—We recorded 18 species of birds breeding in the Deer Creek riparian area; 16 species bred on the grazed site and 18 on the ungrazed site (table 3). No meaningful differences were apparent between grazed and ungrazed sites with respect to either the number of breeding bird species or total breeding bird densities. The total number of breeding pairs in the two riparian habitats was virtually identical. Estimates of bird standing crop biomass between the grazed and ungrazed sites were also nearly the same. There was almost complete overlap in the species breeding on the two sites. The most abundant species were the *Empidonax* flycatcher, American robin, house wren, yellow warbler, broad-tailed hummingbird, and white-crowned sparrow. (Scientific names of birds are given in table 3.) Species richness was slightly higher on the ungrazed site, but species diversity was slightly higher on the grazed site, suggesting little meaningful difference between the two sites.

Summit Creek—We recorded seven species of birds breeding in the Summit Creek riparian area; six species bred on the grazed site and three species bred on the ungrazed site (table 3). Savannah sparrows and western meadowlarks were found as breeding birds under both grazed and ungrazed conditions. Killdeer, willets, long-billed curlews, and Brewer's blackbirds were territorial only on the grazed area. Red-winged blackbirds nested only on the ungrazed area.

We found little difference between the grazed and ungrazed sites in total breeding bird density (table 3). But estimates of total bird biomass differed markedly. Biomass on the grazed site was almost twice that on the ungrazed site (table 3). The difference in total biomass was due to the presence of large shorebirds (killdeer, willet, long-billed curlew) that were breeders only on the grazed site. Species richness and our estimate of bird species diversity (the reciprocal of Simpson's index) were larger on the grazed site, again as a result of the presence of the three shorebirds that established breeding territories only on the grazed site.

Red-winged blackbirds were found as breeding birds only on the ungrazed plot (table 3). Conversely, Brewer's blackbirds were territorial only on the grazed site. Nests of the red-winged blackbird were bound to tall, coarse stalks of beaked sedge found in thick stands near the stream. Heights of beaked sedge communities at the grazed site were considerably reduced as a result of livestock grazing, thereby essentially eliminating potential nesting habitat for red-winged blackbirds. Nests of Brewer's blackbirds were on the ground in tussocks of grasses and forbs or beside clods of dry manure.

Small Mammals

Deer Creek—Eleven species of small mammals were trapped (table 4). Of these, deer mice, western jumping mice, least chipmunks, and Great Basin pocket mice accounted for 82 percent of the total number of individual animals caught. (Scientific names of small mammals are in table 4.) Other species were trapped irregularly or in smaller numbers. Five species, including Townsend's ground squirrel, northern pocket gopher, bushy-tailed woodrat, montane vole, and long-tailed vole, were trapped only in the ungrazed habitat.

The total number of small mammals was a third higher in the ungrazed habitat than on the grazed site. Further, small mammal standing crop biomass, species richness, and species diversity values were also higher inside the exclosure. Each of the 11 species recorded during the study was trapped in the protected site. Only six species were trapped in the grazed habitat.

Summit Creek—Six species of small mammals were trapped during two seasons of study at Summit Creek (table 4). Deer mice and montane voles accounted for over 94 percent of the individual animals. Each species was trapped on both grazed and ungrazed study sites. Other species were caught irregularly and in smaller numbers. Four species—vagrant shrews, water shrews, northern pocket gophers, and Great Basin pocket mice—were trapped only in the ungrazed habitat.

Estimated small mammal density was approximately a third higher in the grazed habitat (table 4). Total biomass values were similar between the grazed and ungrazed sites. However, small mammal species richness and our estimates of small mammal species diversity were larger within the exclosure. Each of the six species recorded during the study was trapped in the ungrazed habitat. Only two species were trapped in the grazed habitat—deer mouse and montane vole.

Deer Creek and Summit Creek Comparison

Differences between Deer Creek and Summit Creek were quite striking. The differential in total ungrazed plant biomass was approximately 25 times (fig. 2). This was due largely to the occurrence of aspen at Deer Creek, although substantial biomass of riparian shrubs occurred there as well (fig. 3). No woody plants were found in the Summit Creek riparian zone.

An unexpected result in the bird communities was that no overlap occurred in riparian nesting bird species. The riparian nesters were completely different between Deer Creek and Summit Creek. A strong component of shorebirds was found on the grazed Summit Creek site; this resulted in an increase in bird species and biomass for that site over the ungrazed site (figs. 4 and 5). A similar response did not occur at Deer Creek.

A large grazing-attributed reduction in the number of small mammal species occurred at both sites (fig. 6). The net effect of this reduction was quite different on the two study sites. On Deer Creek the loss of species on the grazed portion included those animals of greatest body

Table 3—Breeding bird population attributes

| Species | Foraging guild[1] | Nesting guild[2] | Density (pairs/40 ha) | | | |
| | | | Ungrazed | | Grazed | |
			DC	SC	DC	SC
American kestrel (*Falco sparverius*)	GFC	SCN	2.7	0	0	0
Broad-tailed hummingbird (*Selasphorus platycercus*)	FNI	BTN	12.9	0	15.6	0
Lewis' woodpecker (*Melanerpes lewis*)	ASI	PCN	1.8	0	2.2	0
Yellow-bellied sapsucker (*Sphyrapicus varius*)	TDO	PCN	2.7	0	2.7	0
Downy woodpecker (*Picoides pubescens*)	TDI	PCN	3.6	0	.9	0
Northern flicker (*Colaptes auratus*)	GGI	PCN	3.6	0	4.0	0
Empidonax flycatcher[3] (*Empidonax* sp.)	ASI	BTN	45.3	0	33.8	0
Tree swallow (*Tachycineta bicolor*)	AFI	SCN	1.8	0	2.7	0
House wren (*Troglodytes aedon*)	FGI	SCN	11.1	0	23.6	0
American robin (*Turdus migratorius*)	GGI	BTN	19.6	0	16.0	0
European starling (*Sturnus vulgaris*)	GGO	SCN	.4	0	7.6	0
Warbling vireo (*Vireo gilvus*)	FGI	BTN	8.9	0	2.7	0
Yellow warbler (*Dendroica petechia*)	FGI	BTN	16.0	0	16.4	0
MacGillivray's warbler (*Oporornis tolmiei*)	FGI	BTN	4.4	0	0	0
Song sparrow (*Melospiza melodia*)	GGO	GRN	5.3	0	10.7	0
White-crowned sparrow (*Zonotrichia leucophrys*)	GGO	BTN	9.3	0	11.6	0
Northern oriole (*Icterus galbula*)	FGI	DTN	5.8	0	5.3	0
Cassin's finch (*Carpodacus cassinii*)	GGG	CDN	1.8	0	2.2	0
Killdeer (*Charadrius vociferus*)	GGI	GRN	0	0	0	4.4
Willet (*Catoptrophorus semipalmatus*)	SPI	GRN	0	0	0	3.1
Long-billed curlew (*Numenius americanus*)	GFO	GRN	0	0	0	1.8
Savannah sparrow (*Passerculus sandwichensis*)	GFO	GRN	0	39.1	0	24.9
Red-winged blackbird (*Agelaius phoeniceus*)	GFO	CRN	0	12.0	0	0
Western meadowlark (*Sturnella neglecta*)	GGI	GRN	0	8.0	0	6.2
Brewer's blackbird (*Euphagus cyanocephalus*)	GFO	GBN	0	0	0	17.3
Total pairs per 40 ha			157.0	59.1	158.0	57.7
Total individuals per km²			785	296	790	288
Biomass[4] (g/ha)			218	110	225	217
Species richness (*n*)			18	3	16	6
Species diversity (1/pi²)			7.52	2.01	8.76	3.37

[1]After Diem and Zeveloff (1980). GFC = ground feeding carnivore, GGG = ground gleaning granivore, AFI = aerial feeding insectivore, FNI = foliage nectivore-insectivore, TDO = timber drilling omnivore, TDI = timber drilling insectivore, GGI = ground gleaning insectivore, ASI = aerial sally feeding insectivore, GGO = ground gleaning omnivore, FGI = foliage gleaning insectivore.
[2]After Diem and Zeveloff (1980). CRN = cliff, cave, rock, or talus nester, CDN = conifer-deciduous tree nester, SCN = secondary cavity nester, GRN = ground nester, BTN = bush and small tree nester, PCN = primary cavity nester, DTN = deciduous tree nester.
[3]Specific identification of the *Empidonax* flycatcher was not confirmed; most appeared to be the dusky flycatcher (*Empidonax oberholseri*).
[4]Species weights from Dunning (1984).

Table 4—Small mammal population attributes

Species	Foraging guild[1]	Relative abundance (*n*/100 trap nights)				Naive density[2] (*n*/ha)			
		Ungrazed		Grazed		Ungrazed		Grazed	
		DC	SC	DC	SC	DC	SC	DC	SC
Vagrant shrew (*Sorex vagrans*)	INS	0.3	0.1	0.8	0	1.7	0.3	4.4	0
Water shrew (*Sorex palustris*)	INS	.0	.2	0	0	0	.9	0	0
Least chipmunk (*Tamias minimus*)	OMN	.8	0	.2	0	4.4	0	1.0	0
Townsend's ground squirrel (*Spermophilus townsendii*)	OMN	.2	0	0	0	1.0	0	0	0
Golden-mantled ground squirrel (*Spermophilus lateralis*)	OMN	1.2	0	.2	0	6.2	0	1.0	0
Northern pocket gopher (*Thomomys talpoides*)	HER	.2	.1	0	0	1.0	.3	0	0
Great Basin pocket mouse (*Perognathus parvus*)	GRA	.2	.1	.7	0	1.0	.3	3.5	0
Deer mouse (*Peromyscus maniculatus*)	OMN	5.0	2.0	4.2	5.0	26.7	7.1	22.2	17.8
Bushy-tailed woodrat (*Neotoma cinerea*)	HER	.2	0	0	0	1.0	0	0	0
Montane vole (*Microtus montanus*)	HER	.2	1.6	0	.4	1.0	5.9	0	1.5
Long-tailed vole (*Microtus longicaudus*)	HER	.3	0	0	0	1.7	0	0	0
Western jumping mouse (*Zapus princeps*)	OMN	2.8	0	2.3	0	15.1	0	12.4	0
Total naive density (*n*/ha)						60.8	14.8	44.5	19.3
Total standing crop biomass (g/ha)						2,769	294	855	318
Species richness (*n*)						11	6	6	2
Species diversity (1/*pi*²)³						3.62	2.40	2.89	1.16

[1]After Martin and others (1951). INS = insectivore, GRA = granivore, HER = herbivore, OMN = omnivore.
[2]After Johnson and others (1987). Effective trapping area and grid size are assumed to be identical.
[3]After Hill (1973).
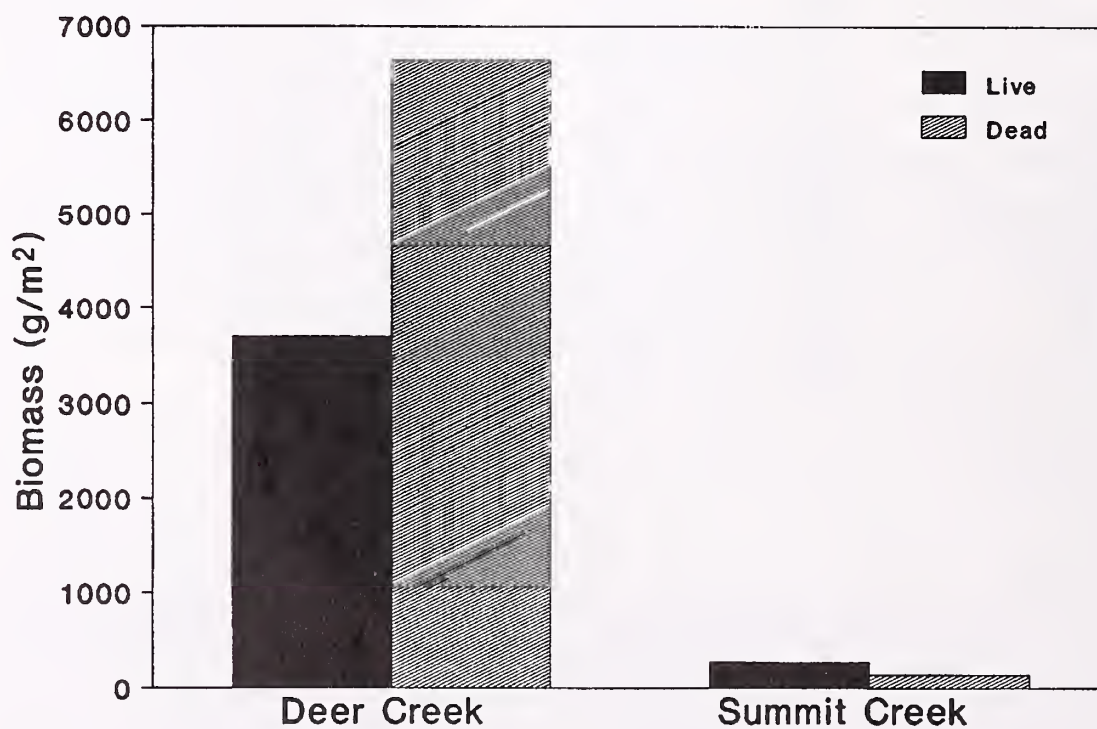[4]Average of 2 years data 1988 and 1989.

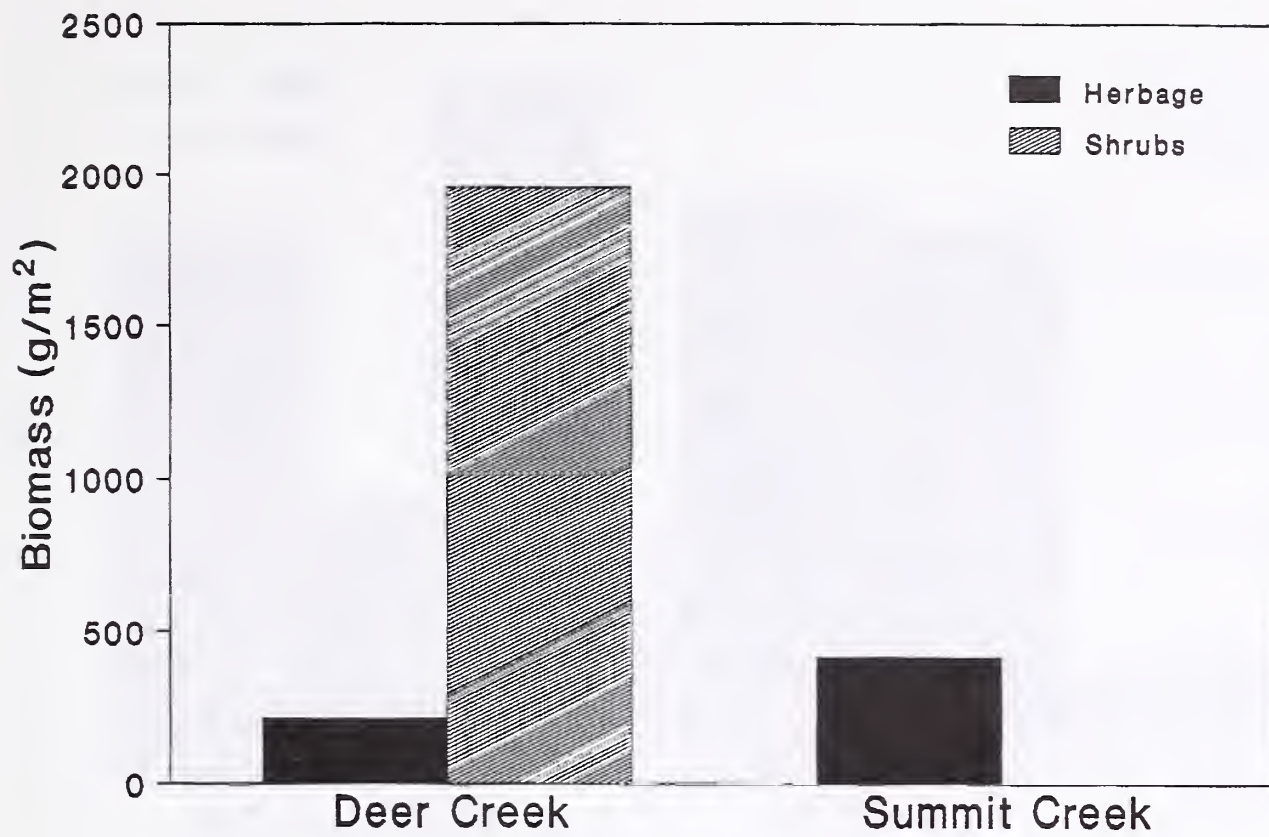Figure 2—Total ungrazed herb-shrub-tree biomass.
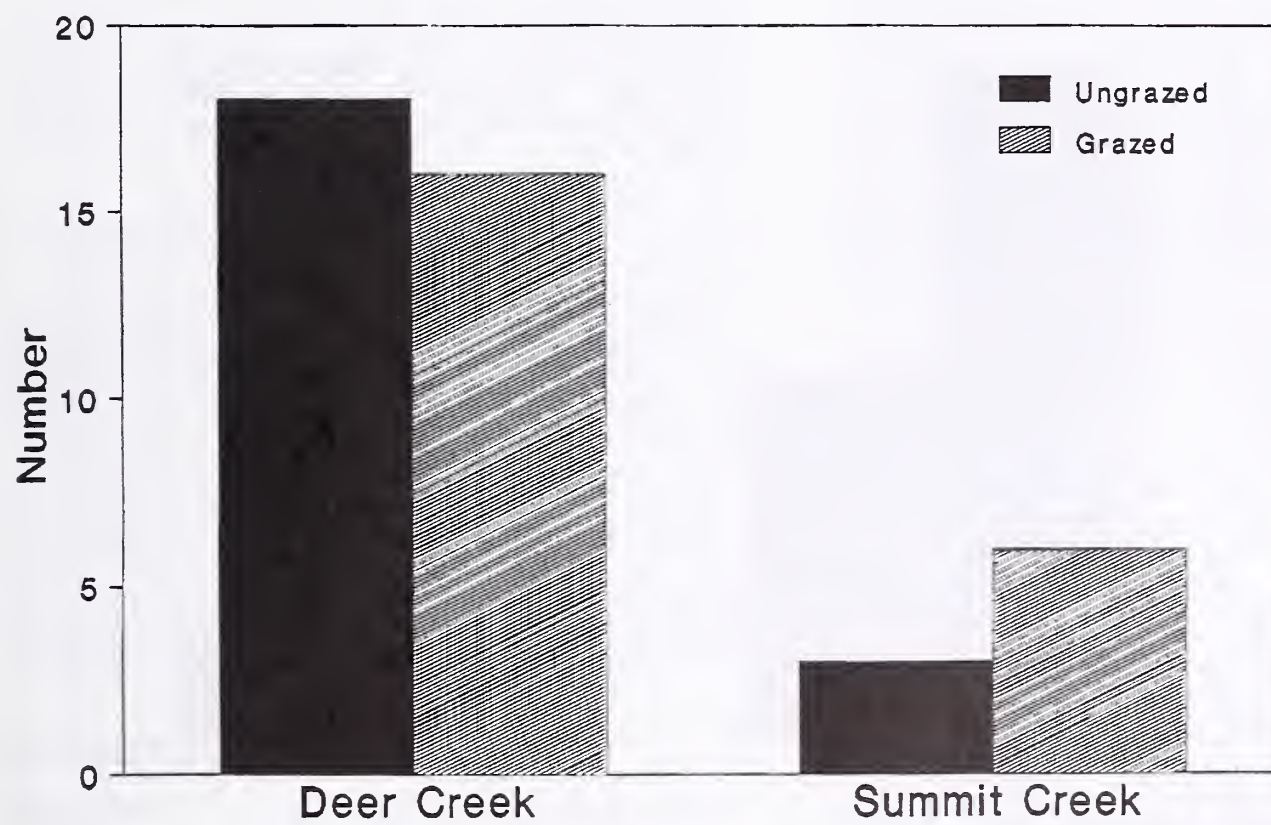
Figure 3—Ungrazed herb-shrub biomass.

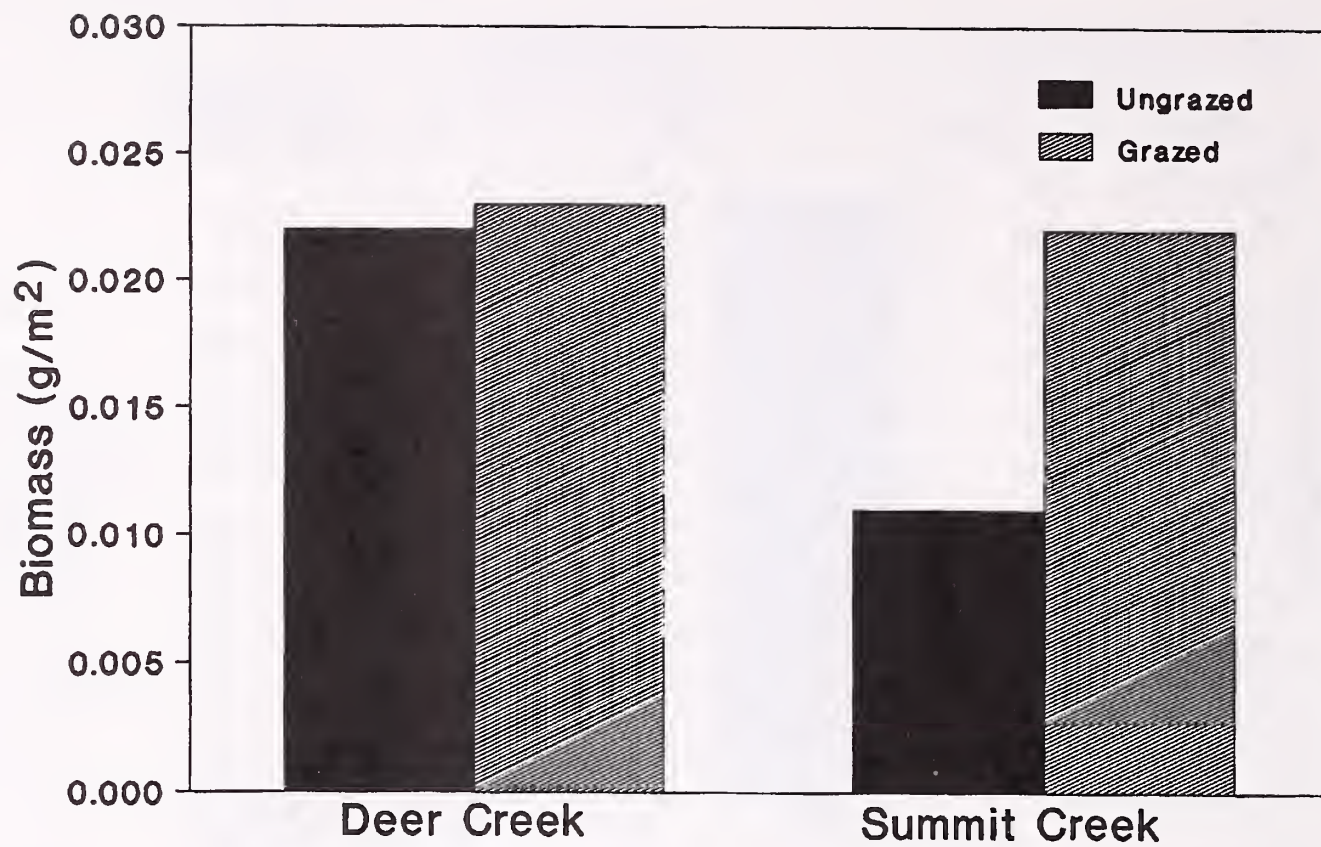**Figure 4**—Song bird species.

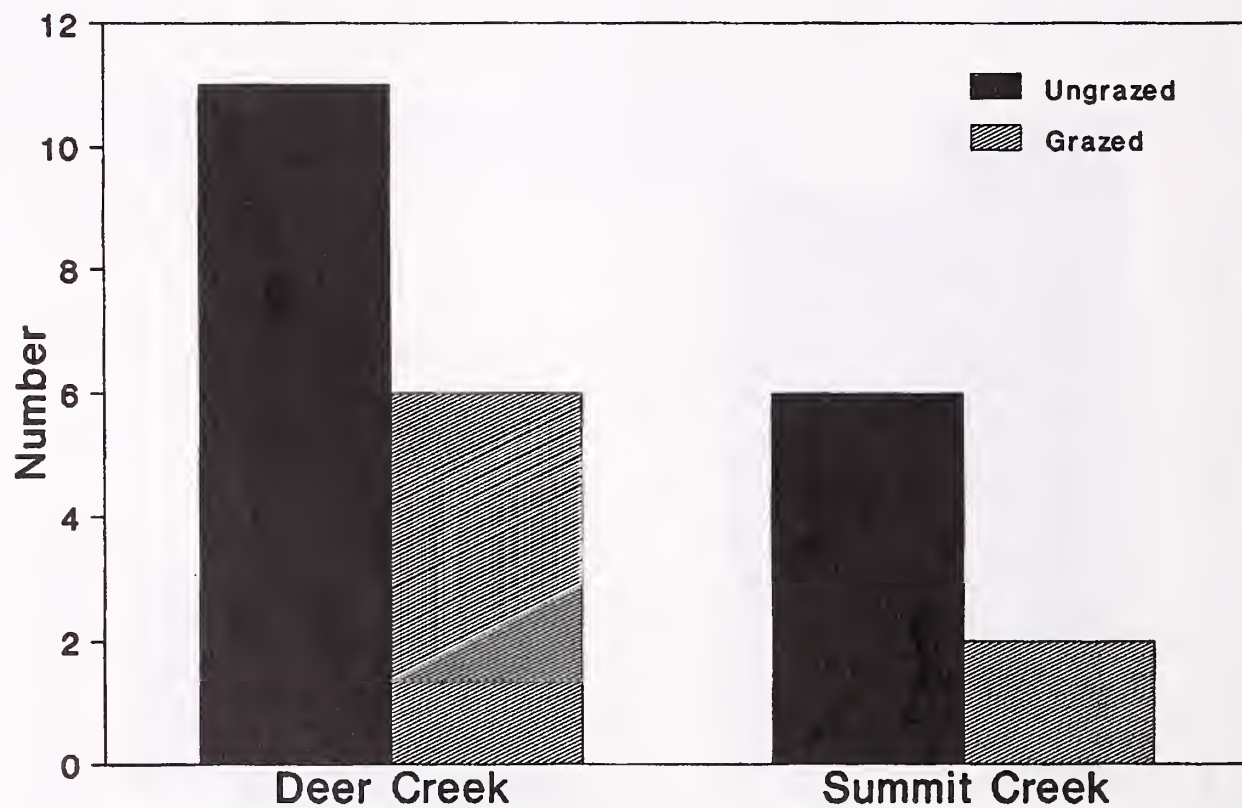**Figure 5**—Song bird biomass.
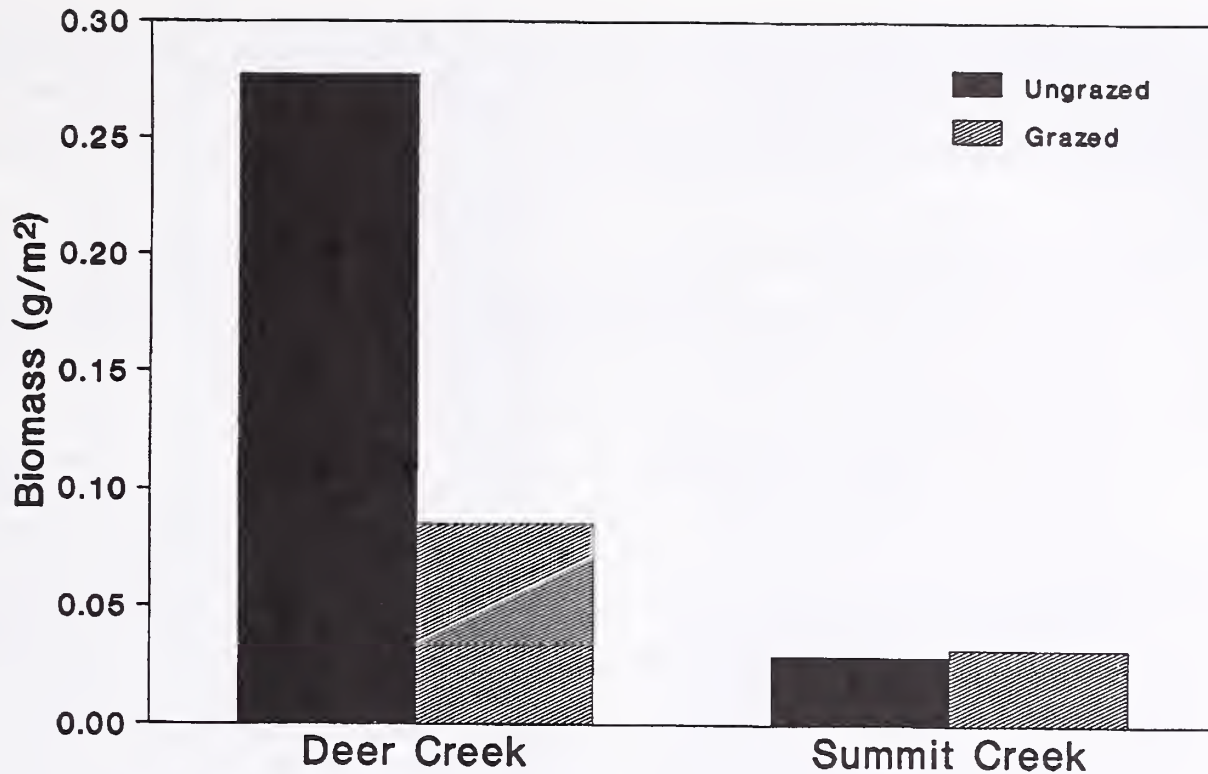

Figure 6—Small mammal species.

Figure 7—Small mammal biomass.

weight, therefore an even larger relative reduction in biomass occurred compared to the ungrazed portion (fig. 7). However, on Summit Creek a shift in populations toward higher total densities in the grazed portions resulted in a similar small mammal biomass for grazed and ungrazed situations on Summit Creek.

CONCLUSIONS

Vegetation characteristics and grazing responses and small mammal and bird populations could not be predicted for either site based on data from the other, even though many environmental conditions were similar. The areas were alike in elevation, general ecological zone, precipitation, and livestock grazing management. The only major environmental difference between the Deer Creek and Summit Creek sites appeared to be geomorphology. The substantial biological differences between the two areas, therefore, seem to be primarily due to the geomorphic conditions, and far exceeded the variation introduced by the impact of livestock grazing.

REFERENCES

Bartos, Dale L.; Johnston, Robert S. 1978. Biomass and nutrient content of quaking aspen at two sites in the Western United States. Forest Science. 24(2): 273-280.

Brown, James K. 1976. Estimating shrub biomass from basal stem diameters. Canadian Journal of Forest Research. 6(2): 153-158.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science. 33(1): 43-64.

DeByle, Norbert V. 1985. Management for esthetics and recreation, forage, water, and wildlife. In: DeByle, Norbert V.; Winokur, Robert P., eds. Aspen: ecology and management in the Western United States. Gen. Tech. Rep. RM-119. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 223-232.

Diem, Kenneth L.; Zeveloff, Samuel I. 1980. Ponderosa pine bird communities. In: DeGraff [DeGraaf], Richard M., tech. coord. Proceedings of the workshop on management of western forests and grasslands for nongame birds; 1980 February 11-14; Salt Lake City, UT. Gen. Tech. Rep. INT-86. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 170-197.

Dunning, John B., Jr. 1984. Body weights of 686 species of North American birds. Monogr. 1. Tucson, AZ: Western Bird Banding Association. 38 p.

Elmore, Wayne. 1988. Stream processes and grazing strategies. Presentation at: Riparian management workshop: challenges and opportunities; 1988 May 3; Elko, NV. Unpublished material on file at: U.S. Department of the Interior, Bureau of Land Management, Prineville, OR.

Gillen, R. L.; Krueger, W. C.; Miller, R. F. 1985. Cattle use of riparian meadows in the Blue Mountains of northeastern Oregon. Journal of Range Management. 38(3): 205-209.

Hill, M. O. 1973. Diversity and evenness: a unifying notation and its consequences. Ecology. 54(2): 427-432.

Hubbard, John P. 1977. Importance of riparian ecosystems: biotic considerations. In: Johnson, R. Roy; Jones,

Dale A., tech. coords. Importance, preservation and management of riparian habitat: a symposium; 1977 July 9; Tucson, AZ. Gen. Tech. Rep. RM-43. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 14-18.

International Bird Census Committee. 1970. An international standard for a mapping method in bird census work. Audubon Field Notes. 24(6): 722-726.

Jahn, Laurence R. 1978. Values of riparian habitats to natural ecosystems. In: Johnson, R. R.; McCormick, J. F., tech. coords. Strategies for protection and management of floodplain wetlands and other riparian ecosystems: proceedings of the symposium; 1978 December 11-13; Pine Mountain, GA. Gen. Tech. Rep. WO-12. Washington, DC: U.S. Department of Agriculture, Forest Service: 157-160.

Johnson, Donald R.; Nydegger, Nicholas C.; Smith, Graham W. 1987. Comparison of movement-based density estimates for Townsend ground squirrels in southwestern Idaho. Journal of Mammology. 68(3): 689-691.

Kauffman, J. Boone; Krueger, William C.; Vavra, Martin. 1982. Impacts of a late season grazing scheme on nongame wildlife in a Wallowa Mountain riparian ecosystem. In: Peek, James M.; Dalke, P. D., eds. Wildlife-livestock relationships symposium: proceedings 10; 1981 April 20-22; Coeur d'Alene, ID. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station: 208-220.

Kirkham, Virgil R. D. 1927. A geologic reconnaissance of Clark and Jefferson and parts of Butte, Custer, Fremont, Lemhi, and Madison Counties, Idaho. Pamphlet 19. Moscow, ID: University of Idaho, Bureau of Mines and Geology. 47 p.

Knopf, Fritz L.; Cannon, Richard W. 1982. Structural resilience of a willow riparian community to changes in grazing practices. In: Peek, James M.; Dalke, P. D., eds. Wildlife-livestock relationships symposium: proceedings 10; 1981 April 20-22; Coeur d'Alene, ID. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station: 198-207.

Martin, Alexander C.; Zim, Herbert S.; Nelson, Arnold L. 1951. American wildlife and plants: a guide to wildlife food habits. New York: Dover Publications. 500 p.

Martin, S. Clark. 1979. Evaluating the impacts of cattle grazing on riparian habitats in the National Forests of Arizona and New Mexico. In: Cope, O. B., ed. Proceedings of the forum—grazing and riparian/stream ecosystems; 1978 November 3-4; Denver, CO. [Vienna, VA]: Trout Unlimited, Inc.: 35-38.

Oelke, Hans. 1981. Limitations of the mapping method. In: Ralph, C. John; Scott, J. Michael, eds. Estimating numbers of terrestrial birds: proceedings, international symposium; 1980 October 26-31; Asilomar, CA. Studies in Avian Biol. 6. Ithaca, NY: Cooper Ornithological Society: 114-118.

Platts, William; Jensen, Sherman; Smith, Frank. 1988. Preliminary classification and inventory of riverine riparian habitats—livestock/fishery study areas, Nevada. Progress Report I. Boise, ID: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 77 p. plus appendixes.

Platts, William S.; Raleigh, Robert F. 1984. Impacts of grazing on wetlands and riparian habitat. In: National Research Council/National Academy of Sciences. Developing strategies for rangeland management. Boulder, CO: Westview Press: 1105-1117.

Rickard, W. H.; Cushing, C. E. 1982. Recovery of streamside woody vegetation after exclusion of livestock grazing. Journal of Range Management. 35(3): 360-361.

Skovlin, Jon M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: National Research Council/National Academy of Sciences. Developing strategies for rangeland management. Boulder, CO: Westview Press: 1001-1103.

Swanson, Sherman. 1988. Riparian values as a focus for range management and vegetation science. In: Tueller, P. T., ed. Vegetation science applications for rangeland analysis and management. Boston: Kluwer Academic Publishers: 425-445.

Taylor, Daniel M. 1986. Effects of cattle grazing on passerine birds nesting in riparian habitat. Journal of Range Management. 39(3): 254-258.

Thomas, Jack Ward; Maser, Chris; Rodiek, Jon E. 1979. Wildlife habitats in managed rangelands—the Great Basin of southeastern Oregon: riparian zones. Gen. Tech. Rep. PNW-80. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 18 p.

U.S. Department of Agriculture, Soil Conservation Service. 1987. Soil description. On file at: U.S. Department of Agriculture, Soil Conservation Service, Salmon, ID. 2 p.

Winward, Alma H.; Padgett, W. G. 1989. Special considerations when classifying riparian areas. In: Ferguson, Dennis E.; Morgan, Penelope; Johnson, Frederic D., comps. Proceedings—land classifications based on vegetation: applications for resource management; 1987 November 17-19; Moscow, ID. Gen. Tech. Rep. INT-257. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 176-179.

EFFECTS OF CATTLE GRAZING SYSTEMS ON WILLOW-DOMINATED PLANT ASSOCIATIONS IN CENTRAL OREGON

Bernard L. Kovalchik
Wayne Elmore

ABSTRACT

Early fur trappers reported seeing extensive willow stands throughout western rangelands. By the early 1900's, many of these stands were severely damaged or eliminated through cattle overuse. The Taylor Grazing Act of 1934 helped improve upland range conditions, but rangeland management strategies have been slow to improve willow riparian zone conditions, a factor largely due to grazing systems that include mid- and late-summer use. Eleven common cattle grazing systems are ranked by their impacts on willow plant associations.

INTRODUCTION

Riparian zones are identified by the presence of vegetation that requires free or unbound water or conditions that are more moist than normal (fig. 1) (Franklin and Dyrness 1973). Riparian zone plant associations on the National Forests of central Oregon were described by Kovalchik (1987). That study described 54 common riparian plant associations and community types, six of which are dominated by tall willows, usually with sedges dominating the ground layer (table 1). Other "rare" willow-dominated associations are not described in this paper. The classification system provides a useful framework by which research and management experience can be applied to specific riparian sites and plant associations and communities.

Better information about the effects of grazing systems on riparian vegetation is needed. Past recommendations have often been general, failing to account for extreme variation in site and vegetation associated with riparian zones. Findings from experiments in small pastures may not apply to large pastures and grazing systems appropriate for one vegetation type may not work on another. To better address riparian management, we have reviewed willow literature and combined pertinent information with practical experience to describe grazing system effects on willow-dominated plant associations in central Oregon. The conclusions are applicable to willow-dominated plant associations in other areas of western rangeland.

STUDY AREA

Effects of grazing systems on willow plant associations were observed within 4,500,000 and 8,300,000 acres of land managed by the Forest Service and Bureau of Land Management (BLM). The area extends from the crest of the Cascade Mountains from Mount Jefferson in the north to the California border in the south and eastward through the Deschutes, Winema, Ochoco, and Fremont National Forests and the Prineville, Burns, and Lakeview Districts of the BLM.

Annual precipitation ranges from about 9 to 60 inches, except in the Cascades where it rises to over 100 inches along the crest. In general, precipitation is substantially less than in areas west of the Cascades due to orographic effects. Most precipitation falls as winter snow. Summers are droughty.

Elevations range from approximately 2,000 to 11,500 feet in an area with remarkable diversity of geology and landforms, including volcanic peaks, fault block mountains, pluvial lake basins, flat-lying and tilted plateaus, outwash plains, and deeply dissected volcanic uplands. Volcanoes and fault block uplifts and tilting have dominated the geologic history of the area for the past 40 million years (Chitwood 1976).

Vegetation types are diverse. Juniper (*Juniperus occidentalis*) and sagebrush (*Artemisia tridentata*) steppe dominate foothills and large intermountain basins and valleys. Ponderosa pine (*Pinus ponderosa*), lodgepole pine (*P. contorta*), Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), white fir (*Abies concolor*), mountain hemlock (*Tsuga mertensiana*), Engelmann spruce (*Picea engelmannii*), and subalpine fir (*A. lasiocarpa*) are prominent forest types in the mountains.

IMPORTANCE OF RIPARIAN ZONES

Riparian zones are a minor landscape component in the extensive, dry uplands of the Western United States (Thomas and others 1979). They generally comprise less than 2 percent of the total area. Periodic flooding, coupled with biotic interactions, has produced heterogenous ecosystems of riparian plant communities varying in age class and seral stages (Kauffman 1987). Riparian ecosystems are rich in plant, animal, and aquatic life (Platts and Nelson 1989; Skinner and others 1986; Thomas and others 1979).

Riparian zones provide preferred habitat for both domestic and wild ungulates because they contain:
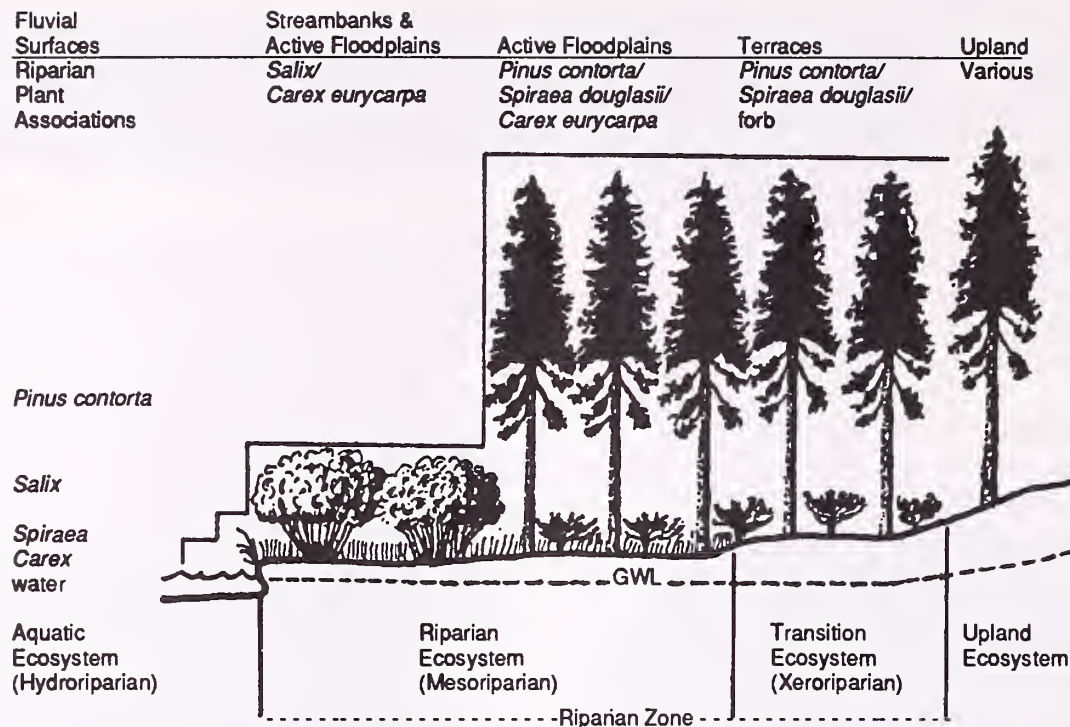
Figure 1—Riparian zones are identified by the presence of vegetation that requires free or unbound water or conditions that are more moist than normal.

Table 1—Constancy[1] and average cover[2] of important plants on six willow-dominated plant associations in central Oregon

Plants	Plant association and number of plots					
	Willow/ Kentucky bluegrass (7)	Willow/ wooly sedge (7)	Willow/ widefruit sedge (19)	Willow/ aquatic sedge (7)	Willow/ Sitka sedge (11)	Willow/ beaked sedge (6)
All shrubs	10(50)	10(63)	10(66)	10(36)	10(64)	10(49)
Bog birch (*Betula glandulosa*)	1(t[3])	......	6(6)	5(4)	5(18)	......
Booth willow (*Salix bebbii*)	......	7(26)	5(25)	5(9)	......	7(32)
Bog blueberry (*Vaccinium occidentalis*)	......	......	3(5)	......	4(9)	......
Douglas spiraea (*Spiraea douglasii*)	......	......	7(10)	......	7(7)	......
Eastwood willow (*Salix eastwoodii*)	......	......	2(6)	......	2(10)	......
Geyer willow (*Salix geyeriana*)	10(32)	7(7)	8(19)	3(5)	6(22)	8(15)
Lemmon willow (*Salix lemmonii*)	3(7)	4(24)	1(t)	3(13)	4(9)	......
All grasses	10(42)	10(16)	10(6)	10(12)	6(2)	10(7)
Kentucky bluegrass (*Poa pratensis*)	10(37)	10(12)	5(1)	7(1)	1(t)	5(1)
All sedges	9(13)	10(38)	10(47)	10(55)	10(61)	10(61)
Aquatic sedge (*Carex aquatilis*)	3(1)	1(1)	......	10(35)	......	2(3)
Beaked sedge (*C. rostrata*)	......	3(1)	5(3)	2(1)	3(6)	8(44)
Inflated sedge (*C. vesicaria*)	1(t)	1(t)	3(3)	......	1(t)	2(6)
Sitka sedge (*C. sitchensis*)	......	......	3(3)	......	10(55)	......
Widefruit sedge (*C. eurycarpa*)	1(t)	......	10(38)	2(1)	2(2)	......
Wooly sedge (*C. lanuginosa*)	3(1)	10(29)	1(1)	2(t)	1(t)	2(2)
All forbs	10(30)	10(28)	10(13)	10(39)	10(8)	10(19)
Common horsetail (*Equisetum arvense*)	1(t)	1(t)	2(t)	2(t)	4(2)	2(t)
Glabrate monkeyflower (*Mimulus guttatus*)	1(t)	1(t)	2(t)	7(2)	......	3(1)
Largeleaved avens (*Geum macrophyllum*)	9(4)	9(2)	4(1)	10(3)	......	5(2)
Longstalk clover (*Trifolium longipes*)	1(3)	3(1)	1(t)	3(5)	......	7(2)
Northwest cinquefoil (*Potentilla gracilis*)	7(2)	4(1)	......	3(1)	......	5(1)
Small bedstraw (*Galium trifidum*)	......	......	5(2)	3(t)	4(1)	5(1)
Starry solomonplume (*Smilacina stellata*)	6(1)	4(2)	2(1)	5(1)	1(t)	3(1)
Sweetscented bedstraw (*Galium triflorum*)	......	6(4)	1(t)	2(t)	1(t)	2(2)
Watson's willowweed (*Epilobium watsonii*)	3(1)	......	3(t)	10(2)	3(t)	7(1)
Western yarrow (*Achillia millefolium*)	9(3)	6(2)	3(1)	7(1)	......	......

[1]Constancy is the percent of plots in which the species occurred. Code to constancy values: 1 = 5-15 percent, 2 = 15-25 percent, 3 = 25-35 percent, 4 = 35-45 percent, 5 = 45-55 percent, 6 = 55-65 percent, 7 = 65-75 percent, 8 = 75-85 percent, 9 = 85-95 percent, 10 = 95-100 percent.
[2]Average canopy cover (in parentheses) is calculated for all plots in each willow-dominated plant association.
[3]t = trace of cover.

- Easily accessible water.
- More favorable terrain.
- Hiding cover.
- Soft soil.
- A more favorable microclimate.
- An abundant supply of lush palatable forage (partially from Behnky and Raleigh 1979; Krueger 1983; Platts and Nelson 1989; Skovlin 1984).

A study in eastern Oregon and Washington found that 1 acre of moist meadow had a grazing capacity equal to that of 10 to 15 acres of upland (Reid 1946). These meadows comprise 1 to 2 percent of the total land area, yet produce about 20 percent of the available summer forage. In a study of a Blue Mountains cattle allotment, Roath and Krueger (1982) found the riparian zone covered 2 percent of the area and produced 20 percent of the summer forage, yet provided 81 percent of the total forage consumed. In this case, utilization was high, as the cattle used 75 percent of the current year's herb growth and 30 to 50 percent of the current year's willow growth in the riparian zone.

IMPORTANCE OF WILLOWS IN RIPARIAN ZONES

Willows are prominent in several riparian plant associations (Kovalchik 1987) (table 1), and they help establish and maintain physical stability and biological diversity in riparian zones (Smith 1980). Willow roots help protect streambanks from erosion while aboveground stems and foliage bend during high flows and dissipate flood energy, thus protecting floodplains from scour erosion (Crouch and others 1987; Crouch and Honeyman 1986; Elmore and Beschta 1987; Platts and others 1987; Skinner and others 1986). Willows also filter overland water flow, trapping sediments from upstream erosion and surface flow from adjacent uplands (Platts and others 1987). In our opinion, streambank stability is largely a function of the effectiveness of riparian vegetation in performing these functions, especially in lower gradient valleys.

Status of Riparian Zones

Fur trappers and explorers reported extensive broadleaf woody vegetation on the floodplains of central Oregon in the early 1880's (Claire and Storch 1973; Storch 1979). With beaver trapping came the first changes caused by people in the structure and function of riparian zones (Kauffman 1987). The elimination of beavers from streams altered site hydrology with subsequent changes in stream processes and riparian habitat. Today, the presence of water, diversity and productivity of plant and wildlife communities, and attraction of people and livestock to the riparian zone continue to cause conflict between various resource uses such as timber harvest, livestock grazing, road location, recreation, mining, and water use (Thomas and others 1979). These uses have greatly altered riparian zones in the past 150 years (Kauffman 1987; Kindschy 1985).

Of these uses, unwise use by livestock is considered the most common cause of deteriorated riparian zones in western rangelands (Knopf and Cannon 1981). Overuse of rangeland in central and eastern Oregon began in the 1860's and first became apparent in the 1880's when severe winter conditions, coupled with depleted forage supplies, resulted in widespread livestock mortality (Kindschy 1987). Livestock abuse was highest during the 1920's as a result of post-World War I reconstruction and increased again with increased red meat demand during World War II (Claire and Storch 1977).

The days of unregulated open range came to an end with the Taylor Grazing Act of 1934. The Act made it possible to control and regulate range use on public lands (Behnke and Raleigh 1979). Improved upland grazing systems were introduced and livestock numbers and length of grazing seasons were reduced (Claire and Storch 1977). Upland range conditions improved in many areas, but not generally in riparian zones. Grazing systems designed for uplands (such as deferred and rotation grazing) have not been effective in riparian zones and are bringing public agencies to legal confrontation with the public over riparian grazing strategies (Behnke and Raleigh 1979).

Status of Willows in Riparian Zones

Willow-dominated plant associations in good condition (dominated by willows and sedges) produce large amounts of forage (2,000 to 5,000 dry pounds per acre, we estimate), yet livestock grazing systems often do not maintain these communities (Smith 1983). Improper use by livestock, sometimes in conjunction with poorly managed big-game herds, has degraded the majority of willow-dominated sites, decreased forage production, and reduced or entirely eliminated willows from many suitable habitats (Kindschy 1985; Kovalchik 1987; Munther 1981; Swenson and Mullins 1985) (figs. 2 and 3). Many older willow stands are dead or dying and little natural regeneration is occurring on poorly managed range allotments.

Figure 2—Silver Creek, Ochoco National Forest, showing streambanks anchored by a good-condition willow/wooly sedge plant association. Geyer and Booth willows dominate the tall shrub layer. The association continues across a wide active floodplain.

Figure 3—Egypt Creek (near Silver Creek), showing severe change in composition due to many decades of season-long grazing. Big and silver sagebrush, Kentucky and Cusick bluegrass, and annual grasses and forbs dominate the now xeric floodplain. Nebraska sedge dominates the dished stream bottom. The vegetation potential is the same as Silver Creek.

WILLOW RESPONSES TO LIVESTOCK GRAZING

Sheep find willows very palatable, but do little damage to stands if good herding practices are followed. Cattle prefer willows less than do sheep, but are more destructive when they congregate in riparian zones (Smith 1982). Since cattle do more damage, the remaining discussion focuses on their grazing.

Mature Willow Responses

Cattle damage willow stands by both browsing and physically breaking lower branches as they seek summer shade and other palatable forage (Knopf and Cannon 1981). Willows become a principal source of cattle browse as other more palatable forage resources are depleted or as the palatability of the alternate forage decreases. Therefore, most browsing damage to willows occurs in late summer (Kauffman and others 1983; Smith 1982). There is little change in protein levels in the twigs of willows (about 7 percent) from early to late summer (Thilenius 1990). Early season upland grasses have crude protein levels of 15 to 17 percent, but levels fall below 5 percent as grasses mature. As this occurs, cattle increase the amount of available palatable forbs and browse in their diets and soon move into the riparian zone. Then a shift to willows occurs as riparian forage supplies become exhausted, usually toward the end of the grazing season. Willow use can also occur earlier in the summer if a range allotment is overstocked for too long. As long as palatable herbaceous forage is available in the riparian zone, willow utilization will remain minor (Kauffman and others 1983).

Our observations for mid- to late-season grazing indicate that cattle begin using the current annual growth on willows when riparian forage use reaches about 45 percent of total available forage (4- to 6-inch stubble height). Use increases again at 65 percent (2 to 4 inches), and cattle eat all the willows they can when utilization is 85 percent or more (<2 inches). Overused willow stands show a "grazing line" where all young shoots have been grazed. With continued overuse, dead and dying plants suggest former willow abundance. Excessive grazing may eliminate a willow stand within 30 years (Kovalchik 1987).

Willow Seedling Responses

First-year willow seedlings are very sensitive to grazing. Shoots and roots at this age are usually less than 12 and 8 inches in length, respectively (authors' observation). Browsing of first-year shoots often kills the entire plant, because the plants are easily pulled from the ground or are killed by trampling. Sites otherwise suitable for willow establishment and growth may be poorly stocked with willow regeneration under inappropriate grazing systems, such as season-long grazing. Poor willow recruitment can retard succession from immature to mature willow stands. Without recruitment, willow stands develop unbalanced age structures and eventually die (Kauffman 1987).

Site Response to Eliminating Stands

Natural erosion of streambanks is a long process and usually occurs in equilibrium with bank rebuilding (Platts 1984). Changes in streambank geomorphology occur as erosion-resistant dominants are replaced by more xerophyllic species such as Kentucky and Cusick bluegrass, big and silver sagebrush, and annual forbs and grasses (fig. 4). Without willow plant associations and their sedge undergrowth, stream channel processes and functions are severely altered (Smith 1980). Under excessive cattle use during the past century this balance has been upset and banks are eroding faster than they can be built. Hydrologic changes in response to altered community composition and grazing include:

- Soil compaction, lower soil infiltration rates, and increased surface erosion.
- Accelerated loss of streamside and instream cover with increasing bank and streambed erosion.
- Increased stream channel capacity with less dissipation of flood energy over the floodplain.
- Straightening of the stream channel resulting in higher water velocity, especially at headcuts and cut meanders.
- Increased peak flow and lower summer flow.
- Increased flood energy causing either downcutting or (if bedrock is near the surface) braiding.
- Lowered floodplain water tables and reduced availability of soil moisture.
- Increased silt deposition on spawning gravels and invertebrate food production areas.
- Increased water temperature (Behnke and Raleigh 1979; Kauffman and Krueger 1984).
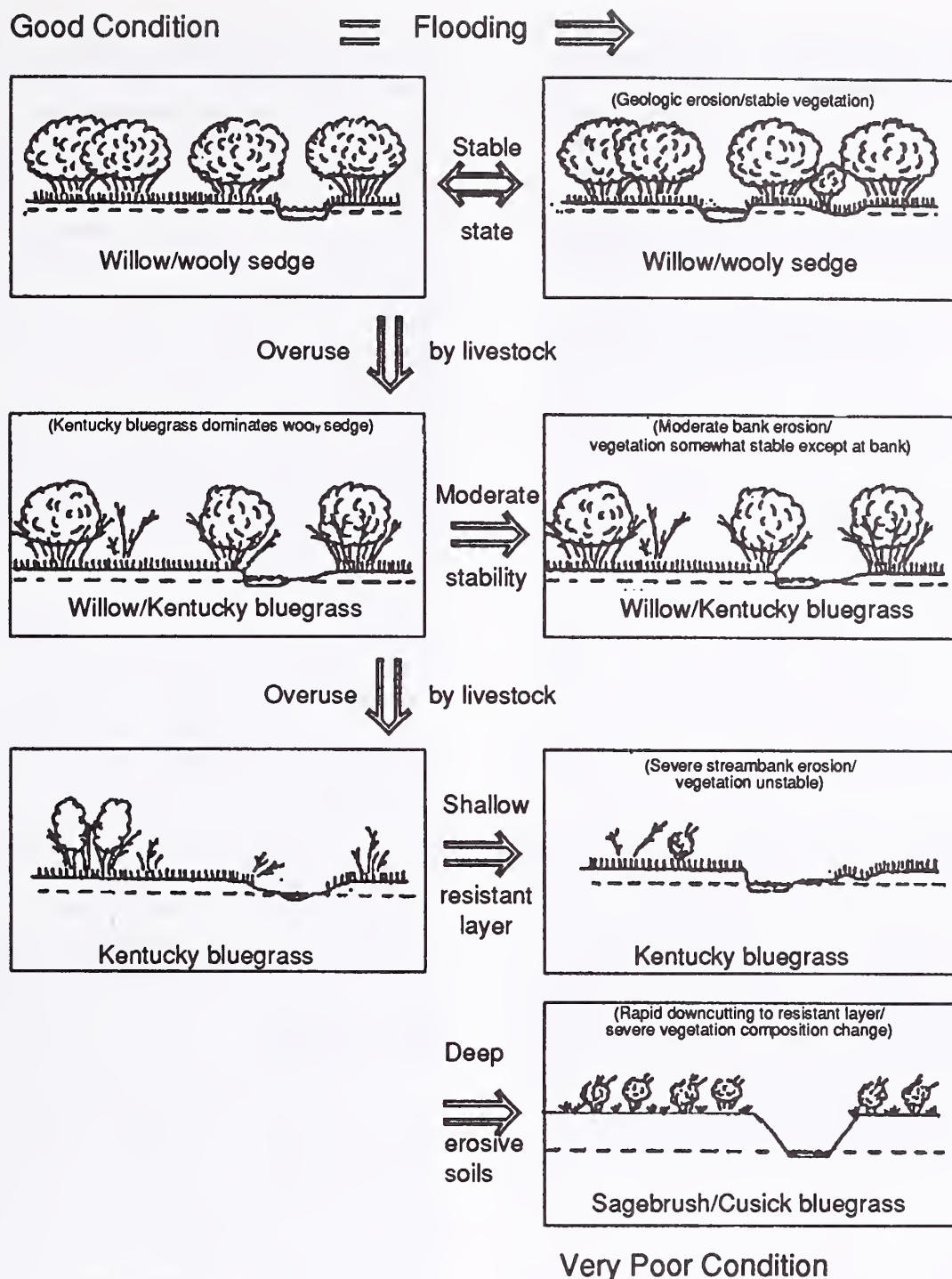
Good Condition   =   Flooding ⟹

Figure 4—Deterioration of sites supporting the willow/wooly sedge plant association with flooding and improper use by livestock.

Eventually, hydrologic changes reach a threshold, after which the stream proceeds into a cycle of gully development or braiding (fig. 4). The opportunity for natural dominants (such as willows) to maintain previous hydrologic conditions and community diversity and productivity is lost. Recovery may take years, decades, or centuries depending on the size and nature of the system and on interim management (Swanson 1989; VanHovern and Jackson 1986).

GRAZING SYSTEMS FOR WILLOW STANDS

To restore forage and willow production in riparian zones, grazing systems must become whole ecosystem-oriented, not just upland-oriented (Kauffman and others 1983; Smith 1981). Most traditional grazing systems were developed for upland grasses and not riparian species (Platts 1986). While grazing systems such as deferred or rotation have improved the condition of most upland range in the last 50 years, they encourage concentrated livestock use in riparian zones during mid- and late-summer periods and have resulted in minimal improvements in riparian conditions (Platts 1986).

Riparian habitats require site-specific management (Platts 1986). Several stream reaches, each with a different mosaic of plant associations and communities, may occur in a single grazing allotment (Kovalchik 1987). These communities have different tolerances to grazing (Behnke and Raleigh 1979). Grazing systems that are compatible

115

with one community may harm another (Kauffman and others 1983). Therefore, to maintain diversity of plant associations along each stream reach, grazing systems must be carefully designed for the communities that are present or desired.

Grazing Systems' Compatibility With Willow-Dominated Plant Associations

In our opinion, the switch from grazing to browsing is the single most important factor in the decline of willow-dominated plant associations to less stable communities (fig. 4). Unless grazing systems allow for sufficient forage height growth during the mid- to late-summer period, they will fail to maintain willow-dominated plant associations. Sufficient forage height acts to prevent excess browsing, provides for regrowth of riparian plants after use, and leaves sufficient vegetation for streambank protection (Clary and Webster 1989).

The degree to which browsing of willows is compatible with long-term stream and plant community maintenance depends on the relative number of willows present. Few willows (where there should be many) should dictate conservative use. Use can be greater where willows are abundant or where management objectives do not call for increased numbers of willows.

The following discussion rates common grazing systems by their effects on willow-dominated plant associations in fair to good condition. The discussion assumes the riparian zone is included within larger upland pastures (except in the cases of corridor fencing and riparian pastures). Discussions refer specifically to ecological requirements of willows and sedges. Rankings partially reflect failures of range managers to effectively manage grazing systems in riparian zones. For instance, incompatible grazing systems might become moderately compatible with willow management if moderate forage height is retained at the end of the summer, an unlikely scenario given past performance.

Highly Compatible Systems

Corridor Fencing—Fencing is the easiest way to obtain rapid improvement in riparian conditions by protecting riparian zones from improper cattle use (Platts and Raleigh 1984). Though fences are expensive to build and maintain, corridor fencing will maintain or restore willow plant associations, even those in poor condition. Fencing may cost less than improper, inappropriately placed, or poorly managed grazing systems (Platts and Raleigh 1984). The BLM has lost only about 8 animal-unit months per mile of fenced stream in central Oregon, an insignificant loss of available forage from grazing allotments (authors' observation).

Response of willow associations to corridor fencing varies greatly between riparian zones. For example, high-sediment watersheds rebuild streambanks more quickly than low-sediment watersheds (authors' observation). An alternative to costly fencing and fence maintenance is to use a willow-compatible grazing system.

Riparian Pasture—Riparian pastures are small pastures set aside to achieve desired vegetation response

(Platts and Nelson 1985). Pastures include enough upland to achieve balanced use between upland and riparian forage. Larger tracts of upland can be used only if managers are willing to write management prescriptions based on riparian considerations alone. In small pastures, all forage is reached with normal cattle movement, encouraging them to go to uplands to vary their diets (Platts and Nelson 1985). Grazing can be controlled more easily when compared to larger pastures, and cattle are removed when forage utilization levels or plant phenology stages are reached (Platts 1984).

If managed properly, the system results in better livestock distribution, grazing intensity, and timing. This leads to increased willow and sedge production and reduced effects on stream morphology (Platts 1986). Willow response is better if the riparian pasture is grazed early or after fall "green up" (regrowth of upland grass following fall rains). Close monitoring of forage use avoids the switch from grazing to browsing.

Spring (Early-Season) Grazing—In the spring, cattle often avoid riparian zones because of cold temperatures, soil wetness, and forage immaturity (Krueger 1983). Therefore, spring grazing encourages cattle to graze uplands where forage maturity and climate are more favorable compared to the riparian zone (Platts 1984). As a result, spring-grazed riparian zones have less than half the cattle occupancy compared to fall use (Krueger 1983). As spring grazing precludes late-summer use, willow browsing is light and seedling survival high.

Response of riparian vegetation is good, even on sites in poor condition. Vigorous willow and sedge regrowth provide excellent streambank protection, and soil and water relationships remain favorable to continued willow and sedge production.

Winter Grazing—Winter grazing is seldom used in mountains because of deep snow. However, it is reasonably compatible with riparian habitat needs and has been used successfully on lower elevation ranges (authors' observation). Riparian forage is not very palatable in the winter and may not receive much use. If used, forage is consumed during the dormant season and there is no regrowth, which results in less sediment trapped during early spring runoff. This potentially negative impact on stream morphology has not been a problem, possibly because soils are frozen and less susceptible to trampling and mass wasting.

Platts (1984) observed little difference between winter pastures and adjacent ungrazed sites except for the larger numbers of willows established on ungrazed sites. Observations vary in central Oregon. Willow seedlings are infrequent on some winter pastures because of browsing and trampling. Best willow establishment and recovery occurs where drainages are colder than adjacent uplands and open south slopes reduce use in the riparian zone.

Moderately Compatible Systems

Two-Pasture Rotation Grazing—Two-pasture rotation grazing is used on BLM lands but apparently not by the Forest Service. The system provides late-summer rest and regrowth on both pastures every year. The very early period of use responds similarly to spring grazing systems.

Use on the critical-season pasture (when the grass flower stalks emerge from the basal meristem) can retard maintenance or recovery of willows if it extends into the hot summer season and results in the shift to browsing.

Pastures respond best to this system if cattle are removed from the critical-use pasture before summer drought, allowing lightly used willows and sedges to regrow through the remainder of the growing season. Two-pasture rotation grazing may not improve pastures in poor condition (authors' observation). Adding years of rest, especially on degraded pastures, and careful monitoring of forage use will increase the effectiveness of the system for willows.

Three-Pasture Rest-Rotation Grazing—Three-pasture rest-rotation allows one pasture to be rested an entire season while the others support the grazing. Sedge communities may respond favorably to this system, as a vegetative mat is left on streambanks in most years (Elmore 1989; Platts 1986). However, the system may not improve either willow or sedge production on pastures in poor condition (Smith 1989). In theory, willows should respond favorably to this system because of the rest period. In practice, 2 or 3 years of willow growth are often removed on the late pasture (Platts 1984).

Smith (1980) and Kindschy (1989) found that less than half of heavily clipped or browsed willow stems survive into the following year. Of the survivors, regrowth was half the growth of ungrazed stems. Therefore, 3 or more years of rest may be necessary for heavily used willows to recover. Adding more rest and removing cattle before 45 percent use of forage in the late-season period will better protect willows when using this system.

Three-Pasture Deferred-Rotation Grazing—Three-pasture deferred-rotation grazing moves cattle from early to critical-season pastures at a predetermined date or at some level of forage use (Platts 1984). The third pasture is used after seeds of upland grasses have ripened, and cattle are removed when desired use of upland grasses is reached. This grazing system seems desirable for sedges because of 2 years of late-summer rest. However, overuse by concentrated cattle may cause sedges to decline, especially if stubble height during spring runoff is too short to resist erosion. In theory, this system is beneficial for willows, with late-season grazing occurring in 1 of 3 years.

Unfortunately, difficulty in managing cattle distribution and forage use often results in a shift to browsing on mid- as well as late-summer pastures, resulting in 2 years of overuse followed by decline in willow cover and vigor (Platts 1984). The system as applied in central Oregon often fails to maintain good-condition willow stands, which degrade to sedge communities or worse. Nor does it improve sites in poor condition. It can be improved for willows by adding more rest and ending mid- and late-season grazing before 45 percent forage use.

Incompatible Systems

Spring-Fall Pastures—Spring-fall pastures are used for a short period in the spring before summer pastures are ready and again in the fall before cattle are moved to winter pasture. Rest occurs during the critical growing season. This system has not maintained or enhanced willow stands in central Oregon because of the late grazing period. If spring-fall grazing is to be effective, attention must be paid to forage use during late-season period.

Spring-fall grazing is acceptable in good-condition riparian zones if early use is ended before the critical growing period, fall use is delayed to forage regrowth on adjacent hillsides, and fall use is ended at 45 percent forage use. Concentrating animals for a short period of time may have the same effect as light grazing and is acceptable for maintaining willow vigor and cover.

Deferred Grazing—Deferred grazing is used where there is a long period of time between the convenience of early season grazing and later maturation of forage plants. For example, sedges may not be convenient for spring grazing because of wet soils, but they continue to regrow and may be used until mid-October or November. If sedge use is ended in September, regrowth can provide substantial cover for streambank protection. However, sites in poor condition (without willows or sedges) have not responded to the deferred grazing system (Smith 1989).

With deferred grazing, cattle soon concentrate in the riparian zone. As riparian forage is overused, use shifts to browsing. Willow stands are converted to sedge communities or worse (Kauffman and others 1983). Removing cattle before 45 percent forage use will improve the usefulness of the system for willows only if willow cover and vigor are already good. Other grazing systems should be used on sites in need of recovery.

Late-Season Grazing—As usually practiced, late-season grazing is not much different than season-long or deferred grazing in its effects on willows (Kauffman and Krueger 1984; Platts 1984). Willow stands soon degrade to sedge communities or worse. Late-season use can be made more effective for willow stands by removing cattle at 45 percent forage use or delaying grazing until regrowth of upland grasses, at which time cool temperatures in riparian zones disperse cattle to uplands.

In theory, the system could be improved by reducing cattle numbers to prevent overuse of riparian forage, a difficult way to reduce riparian grazing at a time when cattle prefer riparian vegetation. The system can be improved for sedges if cattle are removed early enough to allow fall regrowth, thus providing streambank protection during spring runoff. In practice, the system is incompatible with willow and sedge management unless large pastures are grazed solely for riparian objectives and become, in essence, a riparian pasture.

Season-Long Grazing—In the season-long grazing system, livestock are released into an allotment in the early spring (actual time depends on average upland forage readiness and soil conditions) and removed in the fall (Platts 1984). Season-long pastures will not support fair or better condition willow stands. Early use of the pasture is often acceptable for the reasons outlined under spring grazing. However, cattle soon congregate in the riparian zone during the hot summer months. Overuse of riparian forage occurs by mid-summer and cattle use switches to willows, eventually eliminating the stand. In addition, season-long grazing never gives sedges a chance

to replace carbohydrate reserves, and they are soon replaced by increaser plants such as Kentucky bluegrass and unpalatable forbs.

Reducing the number of cattle does not counter the negative impacts of the system, it just prolongs the outcome. The system is incompatible with both willow and sedge management.

SUMMARY

Improper cattle grazing has severely affected the stability of riparian zones, especially those once dominated by willows. There is considerable variation in the effects of common grazing systems on the stability of willows and sedges (fig. 5). Spring grazing is a good example of a system that avoids late-summer use and is compatible with willow management. Compatible systems should be considered where willows have significant cover or where managers wish to restore willows. Moderate-impact grazing systems such as three-pasture rest-rotation were designed for uplands and should be used only where their negative effects on willows can be mitigated by strict enforcement of riparian forage use to prevent the switch from grazing to browsing. Otherwise, their use will result in downward condition trends in willow-dominated plant associations. Systems such as late-season grazing are incompatible with willow management because of late-season use and the switch to browsing. Incompatible systems should be discouraged where the goal of management is to maintain or recover willow stands.

REFERENCES

Behnke, R. J.; Raleigh, R. F. 1979. Grazing and the riparian zone: impact and management perspectives. In: Proceedings, symposium on strategies for protection and management of floodplains, wetlands, and other riparian ecosystems; Atlanta, GA: 263-267.

Claire, E. W.; Storch, R. L. 1977. Streamside management and livestock grazing: an objective look at the situation. Presented at: Wildlife livestock and fisheries workshop; 1977 May 4-6; Reno, NV. 57 p. Unpublished report.

Clary, W. P.; Webster, B. F. 1989. Managing grazing of riparian areas in the Intermountain Region. Gen. Tech. Rep. INT-263. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 11 p.

Crouch, R. J.; Honeyman, M . N. 1986. The relative salt tolerance of willow cuttings. Journal of Soil Conservation. 42(2): 103-104.

Elmore, W. 1989. Riparian management, Oregon recipes. Presented at: Wild Trout IV. 1989 September 18-19; Yellowstone National Park; Mammoth, WY. 6 p.

Elmore, W.; Beschta, R. 1987. Riparian areas: perceptions in management. Rangelands. 9(6): 260-265.

Franklin, J. F.; Dyrness, C. T. 1973. Natural vegetation of Oregon and Washington. Gen. Tech. Rep. PNW-8. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 417 p.

Kauffman, J. B. 1987. The status of riparian habitats in Pacific Northwest forests. In: Raedke, K. J., ed. Streamside management: riparian, wildlife and forestry interactions. Contrib. 59. Seattle, WA: University of Washington, Institute of Forest Resources: 45-55.

Kauffman, J. B.; Krueger, W. C. 1984. Livestock impacts on riparian ecosystems and streamside management implications...a review. Journal of Range Management. 37(5): 430-438.

Kauffman, J. B.; Krueger, W. C.; Vavra, M. 1983. Effects of late season cattle grazing on riparian plant communities. Journal of Range Management. 36(6): 685-691.

Kindschy, R. R. 1985. Response of red willow to beaver use in southeastern Oregon. Journal of Wildlife Management. 49(1): 26-28.

Kindschy, R. R. 1987. Riparian reminiscences. Rangelands. 9(2): 71-74.

Kindschy, R. R. 1989. Regrowth of willows following simulated beaver cutting.Wildlife Society Bulletin. 17: 290-294.

Knopf, F. L.; Cannon, R. W. 1981. Structural resilience of a willow riparian community to changes in grazing practices. In: Proceedings of wildlife-livestock relationships symposium; 1981; Coeur d'Alene, ID. Moscow, ID: University of Idaho: 198-207.

Systems highly compatible with willow management

Corridor fencing	Willows ⇑ Sedges ⇑	Riparian pasture	Willows ⇑ Sedges ⇑
Spring grazing	Willows ⇑ Sedges ⇑	Winter grazing	Willows ⇔ to ⇑ Sedges ⇑

Systems moderately compatible with willow management

Two-pasture rotation	Willows ⇔ to ⇑ Sedges ⇑	Three-pasture rotation	Willows ⇔ to ⇓ Sedges ⇑
Three-pasture deferred rotation	Willows ⇔ to ⇓ Sedges ⇔ to ⇑		

Systems incompatible with willow management

Spring-fall grazing	Willows ⇓ Sedges ⇔ to ⇓	Deferred grazing	Willows ⇔ to ⇓ Sedges ⇔ to ⇓
Late-season grazing	Willows ⇓ Sedges ⇓	Season-long grazing	Willows ⇓ Sedges ⇓

⇑ = highly compatible
⇓ = incompatible
⇔ = no change

Figure 5—Generalized relationships between grazing system and willow and sedge response on willow-dominated plant associations.

Kovalchik, B. L. 1987. Riparian zone associations: Deschutes, Ochoco, Fremont, and Winema National Forests. R6-ECOL-TP-279-87. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 171 p.

Krueger, W. C. 1983. Cattle grazing in managed forests. In: Forestland grazing symposium: 1983 February 23-25; Spokane, WA. 14 p.

Loft, E. R.; Menke, J. W.; Kie, J. G. 1986. Interaction of cattle and deer on mountain rangeland. California Agriculture. 40(1/2): 6-9.

Munther, G. L. 1981. Beaver management in grazed riparian ecosystems. In: Wildlife-livestock relationships symposium; 1981 April 20-22; Coeur d'Alene, ID. Moscow, ID: University of Idaho Forest and Range Experiment Station: 233-241.

Platts, W. S. 1984. Compatibility of livestock grazing strategies with riparian-stream systems. In: Range watershed riparian zones and economics: interrelationships in management and use short course. Corvallis, OR: Oregon State University: 67-74.

Platts, W. S. 1986. Riparian stream management. Transactions Western Section of the Wildlife Society. 22: 90-93.

Platts, W. S.; Nelson, R. L. 1985. Impacts of rest-rotation grazing on streambanks of forested watersheds in Idaho. North American Journal of Fisheries Management. 5: 547-556.

Platts, W. S.; Nelson, R. L. 1989. Characteristics of riparian plant communities with respect to livestock grazing in northeastern Utah. In: Riparian resource management: an educational workshop; 1989 May 8-11; Billings, MT: 73-81.

Platts, W. S.; Raleigh, R. F. 1984. Impacts of grazing on wetlands and riparian habitat. In: Developing strategies for rangeland management. National Research Council. National Academy of Sciences. Boulder, CO: Westview Press: 1105-1117.

Platts, W. S.; [and others]. 1987. Methods for evaluating riparian habitats with applications to management. Gen. Tech. Rep. INT-221. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 124 p.

Reid, E. H. 1946. Gauging mountain meadow range condition in eastern Oregon and eastern Washington. Circ. 748. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 31 p.

Roath, L. R.; Krueger, W. C. 1982. Cattle grazing influence on a mountain riparian zone. Journal of Range Management. 35(1): 100-104.

Skinner, Q. D.; Smith, M. A.; Dodd, J. L.; Rodgers, J. D. 1986. Reversing desertification of riparian zones along cold desert streams. In: Wyoming water and streamside zone conference: Wyoming's water doesn't wait while we debate. 1986; Casper, WY: 95-101.

Skovlin, J. M. 1984. Impacts on grazing of wetlands and riparian habitat: a review of our knowledge. In: Developing strategies for rangeland management. National Research Council. National Academy of Sciences. Boulder, CO: Westview Press: 1001-1103.

Smith, B. H. 1980. Riparian willow management: its problems and potentials, within the scope of multiple use management. Presented to: University of Wyoming—shrub ecology workshop; 1980 June 5-6; Lander, WY. Rock Springs, WY: U.S. Department of the Interior, Bureau of Land Management. 15 p. Unpublished paper.

Smith, B. H. 1981. The ecosystem approach to stream habitat management. In: Rocky Mountain regional soil-water-air-workshop; 1981 February 2-6; Jackson Hole, WY. Rock Springs, WY: U.S. Department of the Interior, Bureau of Land Management. 5 p. Unpublished paper.

Smith, B. H. 1982. Livestock-riparian-fisheries interrelationships; or, functional applications of adaptation for personal survival. In: Proceedings 17th annual meeting American Fisheries Society; 1982 March 3-4; Fort Collins, CO. 4 p.

Smith, B. H. 1983. Restoration of riparian habitats within the BLM-Rock Springs District. Presented to: Native Plants Inc.: Wildlife habitat rehabilitation and reclamation symposium; 1983 January 10-11; Salt Lake City, UT. Rock Springs, WY: U.S. Department of the Interior, Bureau of Land Management. 8 p. Unpublished paper.

Smith, S. 1989. [Personal communication]. Ecologist, U.S. Department of Agriculture, Forest Service, Modock National Forest, Alturas, CA.

Storch, R. L. 1979. Camp Creek, a catalyst in positive management direction for streamsides. John Day, OR: U.S. Department of Agriculture, Forest Service, Malheur National Forest. 13 p. Unpublished paper.

Swanson, S. 1989. Priorities for riparian management. Rangelands. 11(5): 228-230.

Swenson, E. A.; Mullins, C. L. 1985. Revegetating riparian trees in southwestern floodplains. In: Johnson, R. R.; [and others], tech. coords. First North American riparian conference, riparian ecosystems and their management: reconciling conflicting uses; 1985 April 16-18; Tucson, AZ. Gen. Tech. Rep. RM-120. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 135-138.

Thilenius, J. F. 1990. Dimensional weights and forage quality of Barclay willow and sweetgale on moose ranges in the wetlands of the Copper River Delta, Alaska. Forest Ecology and Management. 33/34: 463-483.

Thomas, J. W.; Maser, C.; Burnham, K. P. 1979. Riparian zones: wildlife habitats in managed rangelands—the Great Basin of southeastern Oregon. Gen. Tech. Rep. PNW-80. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 18 p.

VanHovern, B.; Jackson, B. 1986. Concepts in stream riparian rehabilitation. Transactions 51st North American Wildlife and Natural Resource Conference. Washington, DC: Wildlife Management Institute: 280-289.

POLITICAL AND SOCIAL ASPECTS OF RIPARIAN AREA MANAGEMENT

Thomas C. Roberts, Jr.

ABSTRACT

Discusses three reasons why rate of improvement of riparian areas has been as slow as it has and suggests methods to increase the rate of improvement. Impediments to riparian area improvement are institutional and natural resistance to change, mixed land ownership, and lack of incentives. Suggested management changes include improved career tracks, adoption of holistic philosophies, use of volunteers and consensus problem-solving techniques, and better incentives for improving management programs.

INTRODUCTION

I was introduced to riparian area concerns in the mid-1970's while working on the Randolph Grazing Environmental Impact Statement as an economist. I was asked to determine the costs of fencing 7 miles of stream that flowed through Bureau of Land Management (BLM) acreage. I can remember thinking of how expensive it would be to build and maintain those fences. I can also remember what was frequently the description of riparian areas in those days—sacrifice areas.

I know that my philosophies have changed, probably with those of many other range managers. However, in 1984 I can also remember discussing with the executive vice president of the Utah Cattlemen's Association on a Stewardship tour that what was acceptable in the "old days" was no longer acceptable. We can no longer accept what may have been acceptable in the "good old days."

I will outline here some of the reasons why the improvement of riparian areas has been painfully slow and unless there are some changes will probably continue slowly.

The latter-day awareness of riparian issues probably started about 1977 with the Symposium on the Importance, Preservation and Management of the Riparian Habitat in Tucson, AZ. Bill Platts did some of his earlier work in Rich County, UT, back in the 1970's. Since then, there have been numerous symposia, publications, articles, meetings or training sessions, and training modules on riparian habitats and management. In fact, we probably have much of the needed technical information at hand. This growth in information has led to an increasing awareness of the need for riparian area improvement, particularly as this knowledge is shared by the agency personnel. However, the slow rate of change has likely been related to a number of factors, including human nature.

The condition of our riparian areas was probably the first to reflect the pressures of European settlers, and for the same reasons will be the last to reflect the improved management of the upland rangelands. The natural reasons related to domestic and wild animal grazing are basic to the problems, which are increased by human resistance to change.

INHIBITIONS TO CHANGE

Evidence of this resistance to change is shown by numerous self-help programs, such as Weight Watchers. Most people need continual and frequent meetings to change undesirable habits. We, as human, social animals have institutional and individual inhibitions to change. This resistance to change is evident in the agencies, which are now being accused of being too commodity oriented, and in the agricultural or ranching community, which is often accused of being the laggard in concern over the condition of our wildlands.

Riparian area management is or should be part of an overall rangeland management program. To quote Al Winward, "If we manage riparian areas for quality water, most other uses will be well provided for." Although the riparian areas may show improper management for all to see, it is also extremely likely that they are symptomatic of a management regime that has potential for improvement. This may mean a management philosophy that is cognizant of the whole environment—not most of it. It may mean a higher degree of commitment on the agency's part and on the grazer's part. To some extent, riparian issues have become "other duties as assigned" to the agency people, and to the grazers just something more to worry about. This has probably exacerbated the problem.

The main programs have had a strong constituency; the range, wildlife, and forestry programs all have their strong lobby groups. Unfortunately, they are all commodity oriented. The commodity and disjointed nature of funding in the agencies may have contributed to the slow nature of improvement. Riparian area management is not just a range or wildlife or forestry problem, it is a land management problem that needs a holistic approach. To increase the depth of the problem, riparian areas are found in only a few grazing allotments when many grazing allotments are in need of attention by a range staff that is often too small.

The fact that riparian concerns are "environmental" rather than commodity oriented leaves them with a comparatively divided constituency. This new constituency is contrary to what the agencies are accustomed to dealing with. Many people concerned with riparian issues are not going to concern themselves with the funding process, job titles, or grazing or wildlife issues. Often, these factors are

only peripheral to the main issue of good-condition riparian areas. This interest group is growing in number and strength, as we saw last year in Salt Lake City at the BLM's hearing on vegetative treatment. They sometimes are not trained in the ecological sciences and processes and know little of agency complexities. They think that they know what they want, and they want it now. How often do we find ourselves in the same position on an issue, where we know what we want and we want it now? This change in demand is contrary to the funding priorities or needs as we, as agency people, sometimes see them.

This is a problem that Tom Quigley addressed in two recent articles in Rangelands (Quigley 1989; Quigley and Ashton 1990). Are we being shown something that we need to listen to? As noted above, agency people are not the only people that are reluctant to change their methods or philosophies. The agricultural community is one that prides itself on independent thinking. But how often have we read of or known the rancher or farmer that is willing to buy a new implement but is reluctant to try a new idea. Unfortunately, sometimes the agency staff and the agriculturalists are seeing the same reflection in the mirror.

OWNERSHIP PROBLEMS

The mixed land-ownership pattern has also been a problem. In our work in Rich County, riparian area management has been one of our high-visibility concerns. In 1985, the Ogden Standard-Examiner interviewed a Division of Wildlife Resources biologist in Rich County. The article pulled few punches, leaving much unsaid, allowing the pictures to speak for themselves. Some of the land pictured looked devastated. Although the article did describe the difference in land ownership, the pictures left the impression that all of the land was BLM owned and managed. Later a followup article was written with more explanation on the different land ownerships and management problems. Nonetheless, I am sure some damage to reputations was done in the first article, and probably very little education was done in the followup article. In another instance, a permittee fenced his property so that cattle were forced to utilize the riparian area to an extent much higher than they would have otherwise, just in trailing to get to another part of the allotment.

Among Federal land management personnel, the fact that their agencies control only a minority of the riparian areas is well known. This is a legacy of old laws designed to encourage the settlement of the Country. In fact, the remaining riparian areas are but a remnant of what was here prior to settlement. Most riparian areas are under the plow or otherwise obligated. However, the ownership of the land is not always known to the hiking, fishing, or concerned public—some of the new and changing constituency. This means that we as managers will need to work harder to improve what we can and work harder on those skills needed to improve or sell the program to other sectors—private landholders and State, county, and local governments. This may mean that people skills, something that we in agencies may have a hard time documenting or rewarding, may take on a higher importance than they have in the past. It may also mean that we encourage—monetarily—some people to stay in place

for the good of their career and for the good of the land. Rewarding good people for staying in place, rather than discouraging them from staying in place, may be an innovative idea whose time has arrived. Obviously this may mean some changes in thinking, but the payoff could be better managed land and less money spent on transferring people about the country.

INCENTIVES NEEDED

The reluctance to change and the mixed land ownership add up to a large disincentive to improve any riparian area; indeed maybe we should be surprised at the progress that we have made. It may take some imagination or innovation, but an incentive needs to be in place to encourage the improvement of these areas of biological and managerial diversity. We need to find incentives to change our ways of working. Economic incentives work for many people, while altruism works only for a few and only for a limited time. If the grazer could see rewards within a short period of time, or if agency people had as part of their career plans the feature that it paid them to stay in the area, or manage better, we might see faster progress on riparian issues.

Others have often written on the free-market inefficiencies in our system; those that have the legal mandate do not receive the benefits of the improved management, whether it is an agency managing a riparian area, a rancher grazing his livestock on public lands, or a Fish and Game Department managing deer and elk. Although this may be an inefficiency in our economic system, it is not to say that other systems are better, but to realize that we have something to work around. We must focus on the commonalities, and manage for them—clean water, more productive land, and more diversity within the ecological and economic constraints that we have.

POSSIBLE SOLUTIONS

Here are some possible solutions. Regulatory or structural flexibility would assist in permitting economic or career incentives for the agency professionals to remain in an area to continue working on resource problems. Often we give employees much more incentive to leave rather than stay and be effective in their chosen field of work. Possible ideas may be a technical career track, additional job elements, or different job elements recognizing a person's expertise, or even a different job title to encourage a highly skilled person to remain on the job. While funding may be dedicated to different programs, some aspects of management may not need to be.

The increased regulatory flexibility would enable the agencies to examine other radical ideas to encourage the ownership and solution of the problem by the users or ranchers. Perhaps permittees could have some part of the grazing fee waived to avoid using the riparian area, or a conservation organization or Division of Wildlife Resources might offer a substitute for use of the riparian area. As an example, the Division of Wildlife Resources may have a particular time of use for a part of the allotment that may be of interest to the rancher and be willing to trade for some nonuse in the riparian area.

Encouraging the holistic approach to land management may also help the riparian area management problem. We need to encourage a close working relationship between disciplines and programs, rather than one that is adversarial. The tunnel-vision approach that is sometimes used in program management and planning emphasizes the differences, not the commonalities, in goals and needs. The BLM has addressed this problem in the past, but there could be improvements. As an example, the new BLM course "Interdisciplinary Activity Planning" deals specifically with this issue. Maybe the assignment of the allotment with riparian areas needs to be made to the seasoned range conservationist, riparian specialist, and wildlife biologist in combination. Obviously, it would not necessarily be a full-time job, but their work on that allotment could be in concert, as would their rewards or incentives. Riparian concerns are so important and visible that they warrant such intensity of management. We need to emphasize the commonalities, not the differences. The same approach would be used in the agricultural sector, between the grazers, the Fish and Game Department, the Soil Conservation Service, and the Extension Service.

The mixed land-ownership problem also has potential solutions. Indeed, this problem lends itself well to an interagency approach with the involvement of the Forest Service, BLM, and State agencies. It is the type of challenge that cries out for a cooperative and consensus type of approach to problem solving. Once the problem is shared, so will be the responsibility. The consensus approach needs trust and commitment (hence the need for the agency person to be around and committed to the project) to be effective. Doc and Connie Hatfield of eastern Oregon have discussed this type of management in their columns in the Farmer-Stockman magazines. It has also been used with some success in the Oregon Watershed Improvement Coalition.

Not only does the riparian area problem cry out for a consensus-type approach, but there is room for volunteerism also. Volunteerism is a growing factor in many projects today. The agencies now have volunteer coordinators, and many others routinely take calls from groups looking for projects to work on. As an example, on Earth Day 1991, nearly 1,000 people helped plant trees at the Emigration Canyon fire site of 1988, east of Salt Lake City. This massive effort was a cooperative project that was the fruit of Tree Utah and others. Another example is the volunteer spring exclosure fencing work that has been done for two consecutive years by Utah State University students in Rich County. Some factors to improve the success of the projects include the fact that the project must fit the size and skills of the volunteer group, it must not appear as just busy work, and it should be something that offers pride of ownership and the commitment of management. There must be a long-term commitment on the agency's part. The agricultural and recreating public have long memories, often longer than the tenure of the area or district manager. The project or emphasis cannot be perceived as having the duration of a flash in the pan—here today, gone tomorrow.

CONCLUSIONS

I have addressed three reasons why progress on riparian areas has been slower than we would desire:

1. Institutional and natural inhibitions to change, and the political pressures associated with this resistance to change.
2. Mixed land ownership.
3. Lack of incentives to improve or change.

These impediments to improvement can be overcome through innovative management changes, possibly including changed career tracks, holistic management philosophies, volunteer programs, consensus problem-solving techniques, and increased incentives for improved management programs. Increased regulatory flexibility to manage personnel and programs may also be helpful in improving riparian areas.

While these suggestions may not be as flashy as some proposals, they may go far to bring riparian area management to a point where the more technical aspects of riparian area rehabilitation have greater utility.

REFERENCES

Quigley, Thomas M. 1989. Value shifts in multiple use products from rangelands. Rangelands. 11(6): 275-279.
Quigley, Thomas M.; Ashton, Peter G. 1990. Reporting range resource management activities. Rangelands. 12(5): 264-266.

REEVALUATION OF VEGETATIVE COVER CHANGES, EROSION, AND SEDIMENTATION ON TWO WATERSHEDS—1912-1983

Richard Stevens
E. Durant McArthur
James N. Davis

ABSTRACT

Watersheds A and B, on two adjoining depleted subalpine watersheds at the head of Ephraim Canyon, UT, have been under continuous study since 1912. Watershed A has been protected from grazing since 1920. This protection resulted in a rapid increase in plant cover on all but the more depleted areas. Although Watershed A is still in marginal condition, increase in plant cover has resulted in substantial reduction in runoff and sedimentation. In Watershed B, heavy grazing reduced ground cover and changed a fairly stable watershed to a serious flood-source area. Immediate control of summer runoff and sedimentation was achieved with disking, contour trenching, and seeding of grasses and leguminous forbs. Watershed B would now support controlled livestock use without producing runoff and erosion. Watershed stabilization can be much more rapidly accomplished using restoration techniques than long periods of nonuse. Both systems have a place, depending on the urgency of restoration and management objectives.

INTRODUCTION

Two small, depleted watersheds in Ephraim Canyon, UT, on the Great Basin Experimental Range, have been studied since 1912. Research in the watersheds has obtained information on the influence of herbaceous cover and litter on surface runoff, erosion, and sedimentation.

Watershed A has been closed to grazing since 1920, and no restoration techniques have been used to enhance cover. Watershed B was exposed to grazing and cover loss before 1952 when it was disked, trenched, and seeded. Management techniques in Watershed B have restored cover and stability to levels that will allow controlled grazing.

This paper outlines these two approaches to watershed restoration and their results in these two Ephraim Canyon watersheds by evaluating changes in cover type, erosion, and sedimentation in the years 1952, 1958, 1961, and 1983.

LOCATION

Two small complete watersheds named A and B, located in the head of Ephraim Canyon, Sanpete County, UT, have been under continuous study since 1912.

The two watersheds are located about 900 ft apart in a subalpine vegetative zone at 10,000-ft elevation on the crest of the Wasatch Plateau. Both watersheds are complete, separate, and isolated. Neither has a permanent stream. Watershed A average slope is 18.5 percent and occupies 11 acres. Watershed B average slope is 16.3 percent and covers 9 acres (Meeuwig 1960).

Ellison (1954) stated that heavy grazing and accelerated erosion have changed the characteristics of surface soil in much of the Wasatch Plateau subalpine zone. Forsling (1931) estimated that a few inches to as much as 3 ft of soil had been removed from Watersheds A and B prior to 1912. Soils are residual clay and clay loams derived from limestone and bituminous shales.

Precipitation varies considerably, but averages 36 inches annually, with the majority coming as snow (Price and Evans 1937). An average of 6 inches of rain falls during the summer growing season. During July and August high-intensity localized storms occur.

Prior to introduction of livestock in the 1880's Ellison (1954) characterized the subalpine community on the Wasatch Plateau. Seventy to 80 percent of the vegetation consisted of the following broadleaf species: small-leaf angelica (*Angelica pinnata*), Colorado columbine (*Aquilegia caerulea*), rhexia-leaved paintbrush (*Castilleja leonardii*), sulphur painted-cup (*C. sulphurea*), Oregon fleabane (*Erigeron speciosus*), wallflower (*Erysimum elatum*), oneflower helianthella (*Helianthella uniflora*), Utah peavine (*Lathyrus utahensis*), Porter ligusticum (*Ligusticum porteri*), tall bluebell (*Mertensia leonardii*), sweetanise (*Osmorhiza occidentalis*), leafy polemonium (*Polemonium foliosissimum*), low goldenrod (*Solidago ciliosa*), edible valeriam (*Valeriana edulis*), and western valerium (*V. occidentalis*). The remaining vegetation consisted of slender wheatgrass (*Agropyron trachycaulum*), nodding brome (*Bromus anomalus*), mountain brome (*B. carinatus*), oniongrass (*Melica bulbosa*), and mutton bluegrass (*Poa fendleriana*) with only a few shrubs, trees, and annuals.

Ellison (1954) also listed the following species that characterized depleted areas on the plateau: Louisiana sage (*Artemisia ludoviciana*), Richardson geranium (*Geranium richardsonii*), tarweed (*Madia glomerata*), Rydberg penstemon (*Penstemon rydbergii*), Letterman needlegrass (*Stipa lettermanii*), and common dandelion (*Taraxacum officinale*).

Local areas on the Wasatch Plateau have (and had in 1912) different proportions of these and other species. On open areas with deeper soils, tall forbs predominated.

Plant nomenclature follows Plummer and others (1977) and Welsh and others (1987).

METHODS

Vegetative cover of Watersheds A and B has been manipulated with sheep and cattle since 1912 (Forsling 1931; Keck 1972; Meeuwig 1960, 1970; Sampson and Weyl 1918; Stewart and Forsling 1931).

In 1912, Watershed A live cover had been depleted to 16 percent. This was mostly broadleaf herbs. Watershed B cover was reduced to about 40 percent, consisting of a mixture of broadleaf herbs and perennial grasses. Both watersheds were maintained at these levels of live vegetative cover with controlled grazing, using sheep, through eight seasons to 1919. In 1920, livestock were excluded permanently from Watershed A and the range has been allowed to recover naturally since then. From 1920 to 1930 Watershed B was maintained at about 40 percent cover by controlled grazing. By 1924, Watershed A had recovered to an average of about 40 percent cover, similar to that of Watershed B. Between 1924 and 1930 Watershed A cover remained at 40 percent and Watershed B was held to 40 percent. Starting in 1931 Watershed B was exposed to heavy grazing in an effort to reduce cover to the 1912 Watershed A level of 16 percent. This effect was accomplished by 1950. Late in the fall of 1952 Watershed B was disked, some contour furrows were installed on the steeper slopes and the area was seeded at a rate of 20 pounds to the acre. The seed mixture included smooth brome (*Bromus inermis*), meadow foxtail (*Alopecurus pratensis*), orchardgrass (*Dactylis glomerata*), mountain brome (*B. carinatus*), meadow brome (*B. erectus*), 'Nomad' alfalfa (*Medicago sativa*), mountain lupine (*Lupinus alpestris*), and cicer milkvetch (*Astragalus cicer*). Livestock have not grazed Watershed B since it was seeded.

Sediment catchment basins were constructed in 1914 at the lower end of each watershed to measure surface runoff and sedimentation. Larger basins were subsequently built to accommodate the larger volumes of soil that were being delivered (fig. 1).

Vegetative surveys have been made periodically since 1912. Surveys prior to 1951 only estimated or measured live cover. In the early years, the reconnaissance method was employed (Sampson and Weyl 1918). Forsling (1931) used the point method (Levy and Madden 1933) on permanently established transects. Sampling was done along six 98.5-ft transects per watershed in 1983. Ten quadrats (3.281 ft^2) per transect were placed at 3-m intervals along each transect beginning at the 0 point and alternating from the right to the left side of the survey tape. Cover was determined within each 3.281-ft^2 quadrat for each species using a procedure slightly modified from that described by Daubenmire (1959). The modification consisted of adding one extra cover class with a limit of 0 to 1 percent.

Figure 1—Overall view of Watershed B and buildings over sediment catchment basins in: (A) the fall of 1924 and (B) following grazing treatment in 1946.

Analysis of variance with the Student-Neman-Keuls multiple range test was used on the 1957, 1961, and 1983 data.

RESULTS

1912 to 1920—Using sheep, Watershed A vegetative cover was maintained at about 16 percent (fig. 2) and Watershed B cover at about 40 percent. During this period, Watershed A produced six times as much runoff and five times as much sediment as Watershed B (table 1). This period of study was summarized by Sampson and Weyl (1918).

1921 to 1923—Sheep were used to maintain Watershed B at 40 percent cover. Sheep were excluded from Watershed A, and its herbaceous cover recovered from 16 percent to about 30 percent by 1923 and up to 40 percent by 1924. Vegetative recovery on most of Watershed A was fairly rapid, resulting in considerably less runoff and sediment. The more severely depleted steep area, however, showed little improvement (fig. 2). Even with vegetative improvement, Watershed A produced almost three times as much surface runoff and sediment as Watershed B (table 1).

1924 to 1930—Watershed A was ungrazed and cover persisted at 40 percent. Watershed B was grazed to maintain 40 percent cover (fig. 1). Vegetative composition on the two watersheds was somewhat different; B had considerably
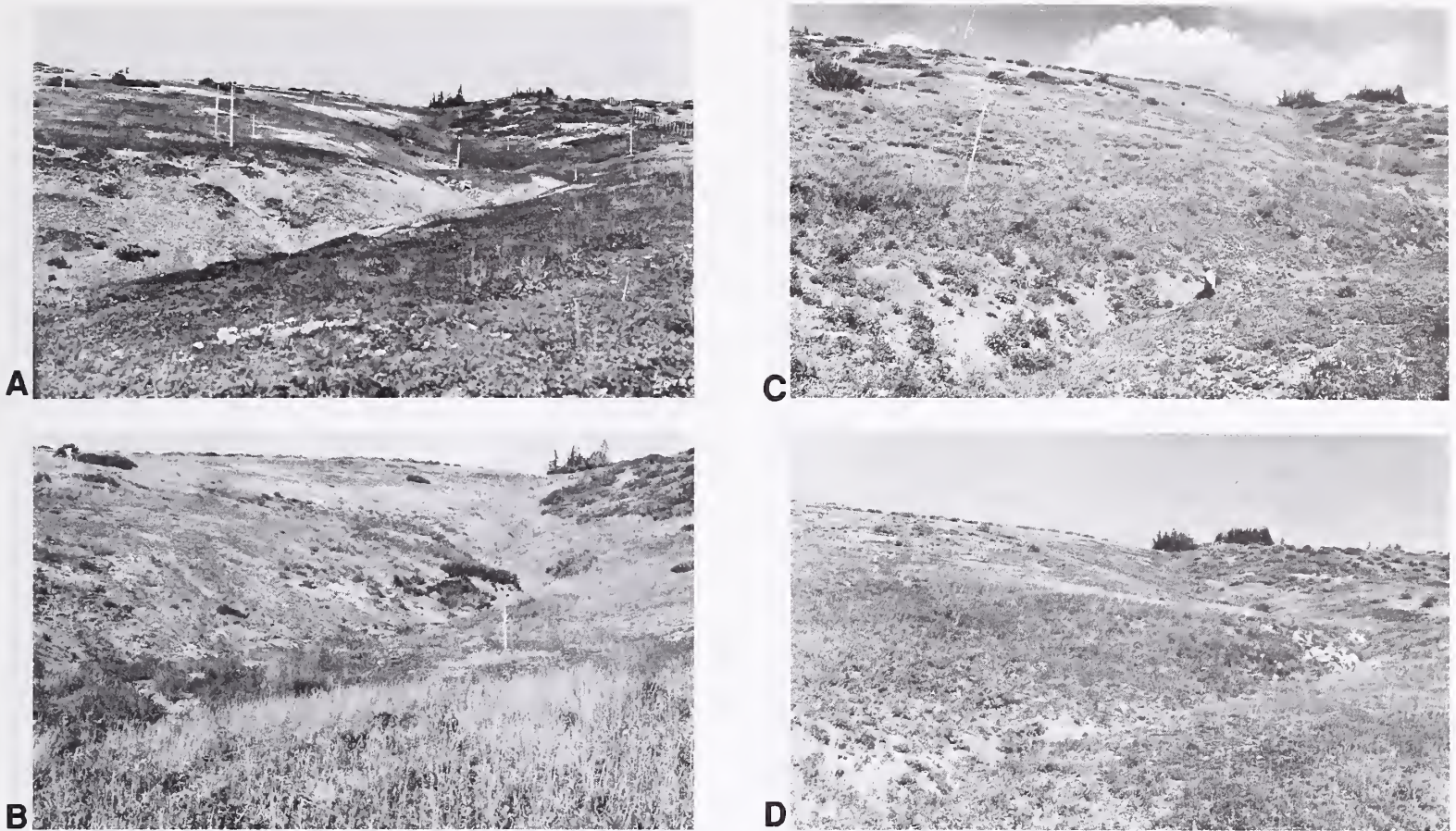
Figure 2—Watershed A in: (A) 1915, (B) 1924, (C) 1940, and (D) 1958.

more perennial forbs and bunchgrasses than A. Watershed A also had steeper areas that were fairly bare and subject to erosion. Forsling (1931) and Stewart and Forsling (1931) summarized work up to 1931.

1931 to 1952—It was felt that the influence of herbaceous cover on surface runoff and erosion could be determined more conclusively if plant cover on Watershed B was reduced to Watershed A's percent cover in 1912 (Meeuwig 1960). During this period Watershed A was ungrazed, and cover remained at 40 percent (fig. 2). Watershed B was heavily grazed by sheep (no grazing during World War II, 1942-45) to reduce plant cover to about 16 percent. This reduction in plant cover resulted in Watershed B producing an average 25 percent more runoff and 40 percent more sediment than Watershed A in 1951. Runoff and sedimentation on A decreased during these years (table 1). Reduction in plant cover and resulting increase in erosion and runoff on Watershed B substantiates the importance herbaceous cover has on watershed stabilization.

1953 to 1957—No grazing occurred on Watershed A. Vegetative cover remained at about 40 percent; most plants were broadleaf herbs (fig. 2). Very little sedimentation has come off A since 1953 (table 1). There has, however, been some summer runoff associated with summer storms. To determine how effective revegetation efforts are in reducing erosion and runoff Watershed B was plowed, furrowed on the steeper slopes, and seeded during the fall of 1952 (fig. 3). The 1952 treatment on Watershed B produced three major results: (1) no summer runoff or sedimentation

after 1953, (2) vegetative community changed from basically a broadleaf herb to a strong grass stand, and (3) gully systems that were prominent were broken up by disking, trenching, and seedling establishment (fig. 3).

Prior to the 1952 restoration treatment on Watershed B, broadleaf herbs accounted for two-thirds of the total vegetative cover. Species in order of abundance in 1952 are given in table 2. Six years following treatment only 6 percent of the vegetative cover consisted of broadleaf herbs, with Louisiana sage being the major forb species. Seeded species made up 90 percent of the vegetation. Meeuwig (1960) summarized data from 1912 to 1958.

1958 to 1983—No grazing occurred on either watershed. As shown in table 3, vegetative cover on Watershed A remained nearly the same until 1983 when it increased significantly. On Watershed B, cover significantly increased in both 1961 and 1983. There was a significant difference in percent vegetative cover between Watersheds A and B in 1958 but no difference between watersheds in 1961 and 1983.

Percent rock (table 3) between 1958, 1961, and 1983 did not significantly change within either watershed or between watersheds. Litter (table 3) percent did not change on Watershed A between 1958, 1961, and 1983. On Watershed B there were significant decreases between 1958, 1961, and 1983. Watershed B, however, had significantly more litter than Watershed A in 1958, 1961, and 1983. Amount of bare ground did not change on Watershed A or B from 1958 through 1961. However, both watersheds had significantly less bare ground in 1983 than

125

Table 1—Grazing treatments, average percent live plant, litter cover, and average annual summer storm runoff and sediment production for Watersheds A and B, 1915 to 1983 (1915 to 1958 data from Meeuwig [1960])

Year	Grazing treatment	Average percent cover			Average annual summer ft³/ac/yr	
		Live plant	Litter	Total	Sediment	Runoff
Watershed A						
1915-20	heavy use	16			134	913
1921-23	no use	30			105	922
1924-30	no use	40			24	362
1931-45	no use	40			20	445
1946-50	no use	40			3	64
1951	no use	44	12	56	3	63
1952	no use	40			16	291
1953[1]	no use	40			60	1,662
1957	no use	40	16	56	T	2
1958	no use	37	17	54	T	17
1961	no use	33	19	52	0	0
1983	no use	53	15	68	0	0
Watershed B						
1915-20	med. use	40			25	153
1921-23	med. use	40			37	260
1924-30	med. use	40			10	171
1931-45		30			29	556
1931-41	heavy use					
1942-45	no use					
1946-50	heavy use	16			36	288
1951	heavy use	14	6	20	102	396
1952[2]	heavy use	15			100	1,376
1953	no use	30			6	553
1957	no use	33	28	61	0	0
1958	no use	25	32	57	0	0
1961	no use	31	26	57	0	0
1983	no use	41	22	63	0	0

[1]Summer storm intensity was the greatest recorded on the watersheds. Intensity of 2.2 inches/h for a 20-minute period.
[2]In October of 1952 Watershed B was disked, trenched on steeper slopes, and seeded to a mixture of grasses and forbs.

Figure 3—Watershed B in: (A) fall 1952 following disking, trenching, and seeding, (B) August 1953 following the highest intensity storm ever recorded and (C) 1954, two growing seasons following seeding.

in 1958 or 1961. There was no difference in percent bare ground between watersheds in any of the 3 years.

The five most abundant species, in order of abundance as determined by percent cover, changed more on Watershed A than on Watershed B (table 2). Watershed A had more species than did Watershed B in all years (table 4). Watershed A had considerably more forbs and fewer grass species than did Watershed B.

In 1958 only 17 ft³/acre of summer runoff and no sediment came off Watershed A. No runoff or sediment was measured off Watershed A in 1961 and 1983, or Watershed B in 1958, 1961, and 1983.

Vegetative cover was closely associated with amount of precipitation on Watersheds A and B. Average water year precipitation on the watersheds over 56 years (1927 through 1983) is 35.95 inches. Precipitation in 1958 (37.79 inches) and 1961 (37.70 inches) was close to average and considerably lower than 1983 (51.72 inches) precipitation. Vegetative cover was significantly higher on A and B in 1983 than in either 1958 or 1961.
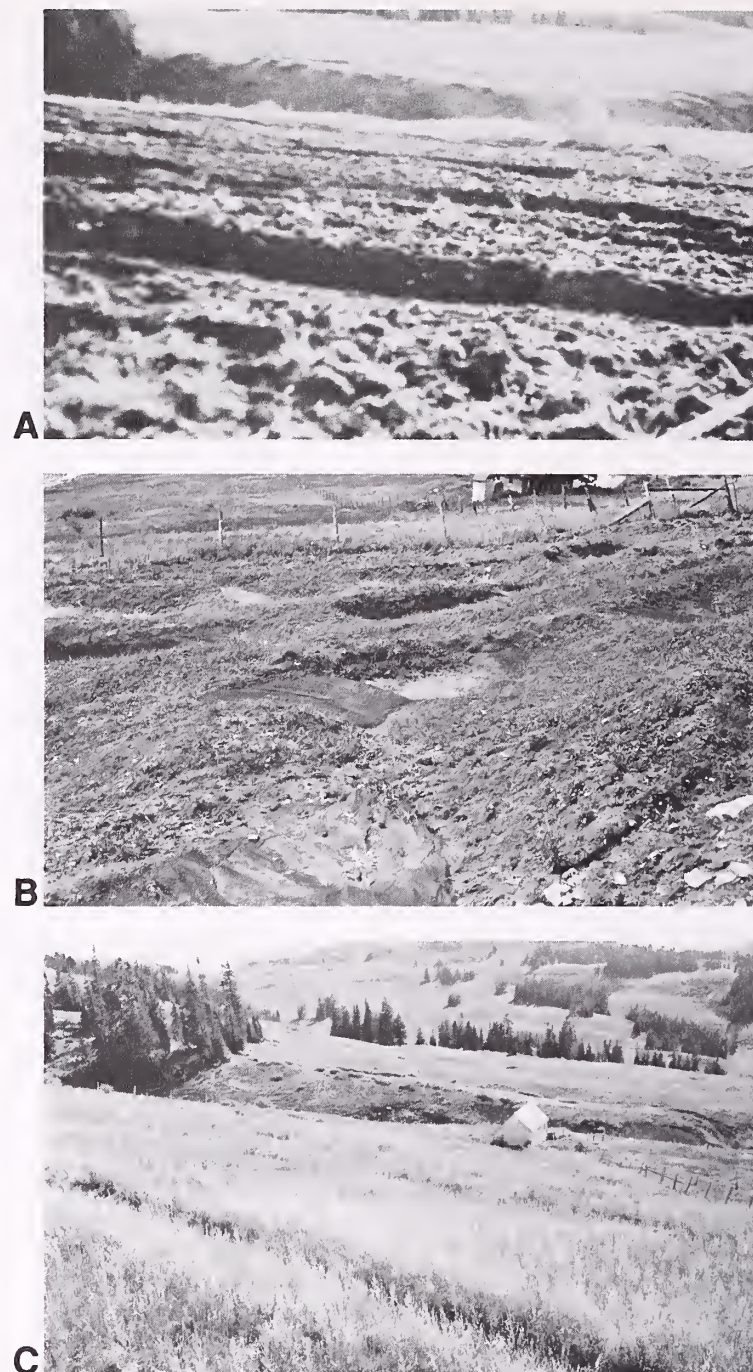
CONCLUSIONS

Runoff and sedimentation on Watersheds A and B are closely associated with vegetative and litter cover. The same associations have also been determined in a number of vegetative types (Dadkhah and Gifford 1990; Gifford 1973, 1985; Meeuwig 1960, 1970; Osborn 1956; Packer 1951; Ward and Bolton 1991; Ward and others 1990; Williams and others 1969, 1972). Infiltration rate and amount of infiltration have also been demonstrated to be positively affected by cover and litter (Blackburn 1973; Orr 1957; Pearse and Wooley 1936; Renard 1970).

Early work on Watersheds A and B (Meeuwig 1960) demonstrated that as cover increases runoff and sedimentation

Table 2—Percent cover of principal species on Watersheds A and B, 1952, 1958, 1961, and 1983

Species	Watershed A 1958	1961	1983	Watershed B 1952	1958	1961	1983
Achillea millefolium	[1]1.4ᵃ	0.9ᵃ	14.2ᵃ [2](1)	(1)	0.4ᵃ	0.3ᵃ	7.7ᵇ (3)
Agropyron trachycaulum	2.8ᵃ (3)	2.3ᵃ (4)	6.6ᵇ (5)		2.8ᵃ (4)	2.4ᵃᵇ (4)	0.6ᵇ
Alopecurus pratensis					3.8ᵃ (3)	4.6ᵃ (3)	0.0ᵇ
Aster foliaceus	2.6ᵃ (4)	0.5ᵃ	5.7ᵇ		0.0ᵃ	0.0ᵃ	2.5ᵇ
Artemisia ludoviciana	2.4ᵃ (5)	2.0ᵃ (5)	7.3ᵇ (4)		0.7ᵃ	1.2ᵃ (5)	3.3ᵇ
Bromus inermis					7.0ᵇ (1)	12.1ᵃ	14.2ᵃ (1)
Dactylis glomerata					1.9ᵇ (5)	0.6ᵃ	0.5ᵃ
Eriogonum umbellatum	2.4ᵃ (5)	2.0ᵃ (5)	0.1ᵃ				
Geranium fremontii	1.9ᵃ	2.0ᵃ (5)	2.5ᵃ				
Lesquerella utahensis				(2)			
Ligusticum porteri	1.7ᵃ	1.4ᵃ	0.7ᵃ				
Lupinus alpestris	2.2ᵃ	3.8ᵃ (1)	5.8ᵃ		0.4ᵃ	0.3ᵃ	4.3ᵇ (5)
Medicago sativa					0.7ᵃ	1.2ᵃ (5)	0.0ᵃ
Penstemon rydbergii	1.6ᵃ	1.7ᵃ	4.1ᵃ				
Phleum pratense				(5)	0.1ᵃ	0.1ᵃ	9.1ᵇ (2)
Poa pratensis	0.9ᵃ	0.2ᵃ	5.6ᵇ		0.1ᵃ	0.0ᵃ	2.0ᵇ
Pseudocymopterus montanus					0.2ᵃ	0.5ᵃ	2.0ᵇ
Ribes montigenum	3.0ᵃ (2)	2.4ᵃ (3)	0.0ᵃ		0.4ᵃ	0.2ᵃ	0.0ᵃ
Stipa lettermanii	0.8ᵃ	1.3ᵃ	9.8ᵇ (2)	(4)	4.2ᵃ (2)	5.7ᵃ (2)	4.6ᵃ (4)
Taraxacum officinale				(3)			
Viguiera multiflora	4.0ᵃ (1)	3.5ᵃ (2)	8.1ᵇ (3)		0.2ᵃ	0.4ᵃ	3.0ᵇ

[1]Numbers in a watershed within the same line followed by the same letters are not significantly different at (P < 0.05).

[2]Numbers in parentheses signify the top five plant species, in order of percent cover, for 1952 (before treatment), 1958, 1961, and 1983.

from grazing, Watershed A produced 60 ft³/acre of sediment and 1,662 ft³/acre of runoff water from the storm. The freshly disturbed and seeded Watershed B only produced 6 ft³/acre of sediment and 553 ft³/acre of runoff water from the same storm.

Difference in percent vegetative cover on Watersheds A and B was not significant ($P > 0.05$) in 1961 and 1983. There was, however, considerable difference in vegetative community composition; A consisted mainly of forbs that do not produce much in-place litter and B supported primarily grasses that produce much more in-place litter. Difference in the type and amount of litter produced between the watersheds is reflected in significantly greater amounts of cover on Watershed B in 1958, 1961, and 1983 than on Watershed A.

Meeuwig (1960), reporting on the condition of the watersheds in 1958, concluded that Watershed A was in marginal condition and would deteriorate if subjected to more than light grazing and that Watershed B appeared to be stable enough to support some degree of controlled grazing. In our judgment, conditions of the watersheds in 1961 and 1983 remained similar to 1958 conditions with respect to animal-carrying capacity and soil stability.

Riparian areas are directly affected by upland site conditions. Management that may include no grazing, limited grazing, or artificial restoration can stabilize erosive areas and reduce sedimentation and destructive, erosive runoff to downslope riparian areas.

Table 3—Vegetation, rock, litter, and bare ground cover percent on Watersheds A and B in 1958, 1961, and 1983

Cover	Watershed A 1958	1961	1983	Watershed B 1958	1961	1983
Vegetative	[1]37.1ᵃ	33.3ᵃ	52.8ᵇ	24.5ᵃ	30.7ᵇ	41.1ᶜ
Rock	10.9ᵃ	10.9ᵃ	8.3ᵃ	11.1ᵃ	11.6ᵃ	17.4ᵃ
Litter	16.5ᵃ	18.8ᵃ	15.1ᵃ	31.5ᵃ	25.6ᵇ	22.3ᶜ
Bare ground	34.6ᵃ	36.9ᵃ	23.8ᵇ	32.0ᵃ	33.1ᵃ	19.3ᵇ

	1958 Watershed A	B	1961 Watershed A	B	1983 Watershed A	B
Vegetative	37.1ᵃ	24.bᵇ	33.3ᵃ	30.7ᵃ	52.8ᵃ	41.1ᵃ
Rock	10.9ᵃ	11.1ᵃ	10.9ᵃ	11.6ᵃ	8.3ᵃ	17.4ᵃ
Litter	16.5ᵃ	31.5ᵇ	18.8ᵃ	25.6ᵇ	15.1ᵃ	22.3ᵇ
Bare ground	34.6ᵃ	32.0ᵃ	36.9ᵃ	33.1ᵃ	23.8ᵃ	19.3ᵃ

[1]Numbers within the same line followed by the same letters are not significantly different ($P < 0.05$).

decrease. When cover decreases the reverse occurs. The forb community of Watershed A has not been grazed since 1920. It took at least 34 years for Watershed A to be stabilized to the point where vegetation and litter were sufficient to intercept and detain surface moisture with no runoff or sedimentation occurring. All runoff and sedimentation was stopped on Watershed B in 1 year with an artificial restoration treatment that included seeding with stabilizing perennial grasses and forbs. The highest intensity storm ever recorded on the Watersheds occurred the summer (1953) following disking, trenching, and seeding of Watershed B. Even with 33 years of protection

Table 4—Number of species encountered on Watersheds A and B in 1958, 1961, and 1983

	Watershed A 1958	1961	1983	Watershed B 1958	1861	1983
Total number of species	43	46	43	32	32	34
grasses	[1]7(16)	8(17)	7(16)	12(38)	10(31)	9(26)
forbs	34(79)	36(80)	36(84)	19(59)	21(66)	25(74)
shrubs	2(5)	2(4)	0(0)	1(3)	1(3)	0(0)

[1]Number in parentheses is percent of total cover.

127

This long-term study has demonstrated that management practices can stabilize depleted subalpine range through long periods of nonuse or rapidly with restoration techniques.

ACKNOWLEDGMENTS

REFERENCES

Blackburn, W. H. 1973. Infiltration rate and sedimentation production of selected plant communities and soils in five rangelands in Nevada. Final Report, Contract No. 14-11-0001-4632. Reno, NV: Nevada Agriculture Experiment Station. 99 p.

Dadkhah, M.; Gifford, G. F. 1990. Influence of vegetation, rock cover, and trampling on infiltration rates and sediment production. Water Resources Bulletin. 16: 979-986.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science. 33: 43-66.

Ellison, Lincoln. 1954. Subalpine vegetation of the Wasatch Plateau. Utah Ecological Monographs. 24: 89-184.

Forsling, C. L. 1931. A study of the influence of herbaceous plant cover on surface runoff and soil erosion in relation to grazing on the Wasatch Plateau in Utah. Tech. Bull. 220. Washington, DC: U.S. Department of Agriculture. 71 p.

Gifford, G. F. 1973. Runoff and sediment yields from runoff plots on chained pinyon-juniper sites in Utah. Journal of Range Management. 26(6): 440-443.

Gifford, G. F. 1985. Cover allocations in rangeland watershed management (a review). In: Jones, E. B.; Ward, T. J., eds. Watershed management in the eighties. New York: American Society of Civil Engineers: 23-31.

Keck, Wendell M. 1972. Great Basin Station—sixty years of progress in range and watershed research. Res. Pap. INT-118. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 48 p.

Levy, E. B.; Madden, E. A. 1933. The points method of pasture analysis. New Zealand Journal of Agriculture. 46: 267-279.

Meeuwig, R. O. 1960. Watersheds A and B—a study of surface runoff and erosion in the subalpine zone of Central Utah. Journal of Forestry. 58: 556-560.

Meeuwig, R. O. 1970. Sheet erosion on intermountain summer ranges. Res. Pap. INT-85. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 25 p.

Orr, H. K. 1957. Effects of plowing and seeding on some forage production and hydrologic characteristics of a subalpine range on central Utah. Res. Pap. INT-47. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 23 p.

Osborn, B. 1956. Cover requirements for the protection of range sites and biota. Journal of Range Management. 9: 75-80.

Packer, P. E. 1951. An approach to watershed protection criteria. Journal of Forestry. 49: 639-644.

Pearse, C. K.; Wooley, S. B. 1936. The influence of range plants cover on the rate of absorption of surface water by soils. Journal of Forestry. 34: 844-847.

Plummer, A. P.; Monsen, S. B.; Stevens, R. 1977. Intermountain range plant names and symbols. Gen. Tech. Rep. INT-38. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 82 p.

Price, R.; Evans, R. B. 1937. Climate of the west front of the Wasatch Plateau in central Utah. Monthly Weather Review. 65: 291-301.

Renard, K. G. 1970. The hydrology of semiarid rangelands watersheds. ARS 41-162. Washington, DC: U.S. Department of Agriculture, Agricultural Research Service. 25 p.

Sampson, Arthur W.; Weyl, Leon H. 1918. Range preservation and its relation to erosion control on western grazing lands. Bull. 675. Washington, DC: U.S. Department of Agriculture. 35 p.

Stewart, George; Forsling, C. L. 1931. Surface runoff and erosion in relation to soil and plant cover on high grazing lands of central Utah. Journal of the American Society of Agronomy. 23: 815-832.

Ward, Timothy J.; Asce, M.; Krammers, J. Sam; Bolton, Susan; Asce, A. N. 1990. A comparison of runoff and sediment yields from bare and vegetated plots using rainfall simulation. In: Watershed planning and analysis in action: Proceedings of symposium; 1990 July 9-11; Durango, CO. New York: American Society of Civil Engineers: 245-255.

Ward, Timothy J.; Bolton, S. M. 1991. Hydrologic parameters for selected soils in Arizona and New Mexico as determined by rainfall simulation. Tech. Compl. Rep. 259. Las Cruces, NM: New Mexico Water Resources Research Institute. 79 p.

Welsh, S. L.; Atwood, N. D.; Higgins, L. C.; Goodrich, S. 1987. A Utah flora. Great Basin Naturalist Memoir No. 9. 894 p.

Williams, G.; Gifford, G. F.; Coltharp, G. B. 1972. Factors influencing infiltration and erosion on chained pinyon-juniper sites in Utah. Journal of Range Management. 25: 201-205.

Williams, G.; Gifford, G. F.; Coltharp, G. B. 1969. Infiltrometers studies on treated vs. untreated pinyon-juniper sites in central Utah. Journal of Range Management. 22: 110-114.

Section 3—Natural and Artificial Rehabilitation of Riparian Areas

245

RECRUITMENT AND GROWTH OF PACIFIC WILLOW AND SANDBAR WILLOW SEEDLINGS IN RESPONSE TO SEASON AND INTENSITY OF CATTLE GRAZING

Nancy L. Shaw

ABSTRACT

The effect of cattle grazing treatments on recruitment and growth of Pacific willow (Salix lasiandra) *and sandbar willow* (S. exigua) *seedlings was monitored over a 4-year period on a degraded low-elevation stream in the sagebrush-steppe zone of eastern Oregon. Treatments included: (1) spring grazing, light-to-moderate intensity; (2) fall grazing, light-to-moderate intensity; (3) protection from cattle grazing; and (4) continued season-long, heavy to very heavy grazing (control). Density of Pacific willow seedlings did not vary among treatments or years. Increase in sandbar willow seedling density over time was similar for the spring grazing, fall grazing, and protected treatments, but declined over time in control pastures. Within species, seedling growth was similar in spring, fall, and protected pastures, exceeding that of controls. However, after 4 years of treatment, heavy deer browsing in all pastures prevented most seedlings from growing beyond the reach of grazing animals, thus establishment was not ensured.*

INTRODUCTION

Ribbonlike springfed streams (stringers) are a common feature of sagebrush-dominated landscapes in the Western United States. Damage to these streams and associated riparian areas from improper livestock grazing practices and other human activities has impaired watershed function, decreased biological diversity, and adversely impacted human economic and recreational activities both locally and downstream (Kauffman and Krueger 1984; Skovlin 1984; Thomas and others 1979). Improving a significant proportion of these streams presents a major challenge. Artificial rehabilitation is often costly, not always successful, and generally applied only to critical areas. The ability of streams and associated vegetation to recover naturally in the absence of livestock grazing or with altered grazing practices is situation specific and related to site characteristics, degree of degradation, availability of seed and vegetative material of native species

adapted to the disturbances, and compatibility of management practices with recovery processes (Crouse and Kindschy 1984; Van Haveren and Jackson 1986). Factors such as wildlife use and presence of weedy species can have profound impacts on the rate, extent, and direction of recovery.

Recent research efforts have been directed toward developing a better understanding of changes in physical stream characteristics and the composition, structure, and productivity of riparian vegetation in response to protection from livestock grazing or to specific seasons and intensities of grazing (Clary 1990; Kauffman and others 1983a, b; Marlow and others 1989; Platts and others 1987). Improved knowledge of the autecology of major riparian plant species, particularly requirements for their establishment and seedling development as well as the response of individual species to grazing practices would contribute to this effort (Patton 1977).

Pacific willow (*Salix lasiandra*) and sandbar willow (*S. exigua*) are two of the most common woody riparian species at low- to mid-elevations within the sagebrush steppe. Pacific willow ranges in growth habit from multistemmed shrubs to tree-like forms. It resprouts following crown removal, but does not spread by suckering (Argus 1973; Haeussler and Coates 1986; Zasada 1986). Stands typically occur immediately adjacent to the water's edge on sites with high water tables year round (Brunsfeld and Johnson 1985; Uchytil 1989b). Sandbar willow is a short-lived, normally shrubby species that forms dense clonal thickets by production of shoots from buds on lateral roots (Argus 1973). It is highly tolerant of flooding and may occur below the high water line (Brunsfeld and Johnson 1985; Hansen and others 1988a). A widely adapted species, sandbar willow may be found bordering margins of rivers, streams, ponds, marshy areas, and irrigation ditches (Dorn 1977; Hansen and others 1988a; Stephens 1973; Uchytil 1989a; Youngblood and others 1985).

Pacific willow and sandbar willow provide streambank stabilization as well as cover and food for numerous wildlife species (Finch 1987; Hansen and others 1988a; Uchytil 1989a, b). Both rapidly colonize fresh alluvial deposits ranging from fine silt to sand and gravel (Dorn 1977; Hansen and others 1988a; Stephens 1973). The objective of this study was to examine recruitment and growth of Pacific willow and sandbar willow seedlings on a degraded low-elevation eastern Oregon stream of the sagebrush-steppe zone in response to season and intensity of cattle grazing.

STUDY SITE

The study was conducted approximately 48 km northwest of Vale in Malheur County, OR. Pole Creek, a spring-fed, third-order tributary of the Malheur River, originates on the eastern slope of the Cottonwood Mountains. The stream is perennial with a rather uniform flow of about 1 cfs. Experimental pastures were installed along a portion of the stream passing through moderate to steep foothill terrain near the base of the mountains. Elevation within the study area ranges from 880 to 975 m. Climate is semiarid. Average annual temperature at Vale, the nearest reporting station, is 10 °C. Mean January temperature is –3 °C and mean July temperature is 23 °C. Average annual precipitation is 244 mm with 61 percent falling from October through March (USDC 1986-90). High intensity, short-duration rain storms are not uncommon in summer.

Soils within the study site are derived from basalt and rhyolite. They range from shallow and rocky on ridges to deep alluvial deposits in former wet meadows and near the mouths of lateral drainages. Uplands support primarily a Wyoming big sagebrush/cheatgrass (*Artemisia tridentata* ssp. *wyomingensis/Bromus tectorum*) biotic climax. Associated overstory shrubs include squawapple (*Peraphyllum ramosissimum*), rubber rabbitbrush (*Chrysothamnus nauseosus*), and an occasional antelope bitterbrush (*Purshia tridentata*), spiny hopsage (*Grayia spinosa*), or Saskatoon serviceberry (*Amelanchier alnifolia*). Sandberg bluegrass (*Poa secunda*), bottlebrush squirreltail (*Sitanion hystrix*), and minor amounts of bluebunch wheatgrass (*Agropyron spicatum*) and Great Basin wildrye (*Elymus cinereus*) are present in the understory. A stiff sagebrush/Sandberg bluegrass (*Artemisia rigida/Poa secunda*) habitat type is restricted to rocky, basalt sites with shallow soils.

Loss of native bank-stabilizing riparian vegetation has resulted in heavy sediment loss and downcutting of the stream channel to bedrock along much of its length. Incised banks sometimes exceed 6 m in height, but are more commonly 1 to 3 m high. The narrow floodplain averages 10 to 30 m in width. Rock and fine- to coarse-textured sediment deposits occur at streamside. Saturated streambars are initially colonized by a field horsetail (*Equisetum arvense*) and water speedwell (*Veronica anagallis-aquatica*) community. These areas are often reworked by later floods. Low terraces with fine- to medium-textured sediments support Kentucky bluegrass (*Poa pratensis*) and redtop (*Agrostis alba*) communities. Drier sites support a number of pioneer species and introduced weeds including flannel mullein (*Verbascum thapsus*) and Scotch thistle (*Onopordum acanthium*). These herbaceous communities intergrade with upland sagebrush communities.

Remnant plants, logs, and seedlings suggest that before livestock grazing populations of woody riparian species along Pole Creek may have been similar to those now present on local streams with relatively healthy riparian areas. The willow family is represented by Pacific willow, sandbar willow, black cottonwood (*Populus trichocarpa*), and narrow-leaf cottonwood (*P. angustifolia*). Shrubs associated with the riparian area include blueberry elder

(*Sambucus cerulea*), Woods rose (*Rosa woodsii*), common chokecherry (*Prunus virginiana melanocarpa*), syringa (*Philadelphus lewisii*), clematis (*Clematis ligusticifolia*), and red-osier dogwood (*Cornus stolonifera*). These shrubs are either heavily grazed or grow in locations inaccessible to livestock.

The Poall Creek grazing allotment comprises 1,829 ha. Approximately 66 percent is within the U.S. Department of the Interior, Bureau of Land Management, Vale District, while the remainder consists of State and private holdings (USDI 1982). The single-pasture community allotment is administered by the Bureau of Land Management and used by three permittees. Active preference is 589 AUM's (USDI 1987). Season of use is April 1 to September 30 in even years and July 1 to October 31 in odd years. Grazing is heavily concentrated along Pole Creek.

METHODS

Grazing treatments were applied to pastures installed along a 5-km segment of the stream. Treatments were: (1) spring grazing, light-to-moderate intensity; (2) fall grazing, light-to-moderate intensity; (3) protection from cattle grazing; and (4) season-long, heavy to very heavy use (control) (table 1). Pastures assigned spring, fall, and protected treatments were fenced to exclude livestock, but not big game. Application of spring and fall grazing treatments normally involved release of four cow/calf pairs into each pasture for approximately 10 days. Treatment duration was determined by monitoring forage utilization by weight at streamside, primarily in Kentucky bluegrass and redtop communities (Clary 1987, 1989). Cattle were excluded from protected pastures. Control pastures were not fenced. They were located approximately 0.5 km from the nearest fenced pastures to avoid a "water gap" concentration effect in their use. Control pastures were grazed with the remainder of the allotment as prescribed in the current Allotment Management Plan (USDI 1982, 1987). Treatments were applied in a completely randomized design with two replications.

Natural recruitment and growth of native woody riparian species were measured annually in early October from 1987 through 1990 on 20 belt transects (each 5-m wide)

Table 1—Grazing treatments applied at Pole Creek Experimental Pastures

Season of grazing	Stocking intensity[1]	Period of use (approximate)
Spring	Light/moderate	May 15-25
Fall	Light/moderate	October 10-20
Protected	Not grazed	—
Season long (control)	Heavy/very heavy	Even years: April 1 - September 30
		Odd years: July 1 - October 31

[1]Based on forage utilization by weight at streamside: light = 20-35 percent, moderate = 36-55 percent, heavy = 56-75 percent, very heavy = >75 percent.

along the approximately 200-m stream segment within each pasture. Transects were placed perpendicular to the stream. Species, height, maximum and minimum crown diameters, number of basal stems and distance from water were recorded for each seedling. Use by livestock or wildlife was noted. Width of active and slack water and the band of stream-affected vegetation were determined for each transect. Precipitation was measured at Brogan, OR, approximately 3 km southeast of the study site, throughout the study period.

Plant density and growth data within and between years were analyzed by analysis of variance (ANOVA). Mean comparisons were made using Fisher's Least Significant Difference (FLSD). Comparisons between years were analyzed as a split plot using conservative degrees of freedom. Significance was noted at the $p \leq 0.05$ level.

RESULTS

Precipitation was erratic throughout the study period. The long-term average precipitation for Vale, the nearest reporting station, is 251 mm (USDC 1986-90) (fig. 1). Average annual precipitation at Brogan from 1986 to 1990 was 226 mm. Brogan rainfall for the 1988-89 water year was 124 percent of normal for Vale but ranged from 67 to 82 percent of the Vale average in the remaining 3 years.

Winter snowpacks and spring runoff on Pole Creek were very light throughout the study period. Spring runoff generally peaked in early March. Intense, short-duration summer rain storms exceeding 20 mm in less than 1 hour occurred in May and August 1987, May and September 1989, and August 1990. These storms caused flash floods that produced sheet erosion and gullying on uplands and severe scouring in and along the stream.

A large number of Pacific willow and sandbar willow seedlings emerged in all treatments during the summer of 1987, possibly because a May flash flood left fresh deposits of saturated sediments along the stream prior to willow seed maturation and dispersal. These deposits were devoid of competing vegetation and provided excellent seedbed conditions for willows. Willow seedlings emerged within a narrow band along the stream, primarily on streambars. They also occurred on saturated sediments colonized by field horsetails and water speedwell and in slack water. Seedlings were not observed in Kentucky bluegrass or redtop communities. In 1990 average distance of seedlings from water, 136 cm for Pacific willow and 90 cm for sandbar willow, did not differ among treatments for either willow species.

Density of Pacific willow seedlings did not respond to treatments or time over the 4 years of study. Analysis of 1990 data alone also failed to distinguish differences among treatments. Density of Pacific willow seedlings averaged over all years and treatments was 1,018/ha of stream-affected vegetation.

Analysis of changes in density of sandbar willow seedlings over time revealed a significant two-way interaction between treatments and years (fig. 2). There was a trend for seedling density in reduced spring grazing, fall grazing, and protected pastures to increase over time, with the rate of increase greatest for spring-grazed pastures. Density decreased over time in control pastures.

Changes in seedling height were similar for both willow species (figs. 3, 4). Significant differences were distinguished among main-effect means for both time and treatments. Height of seedlings in reduced grazing pastures exceeded controls. Mean height differed for each year of treatment with maximum heights measured in 1989.
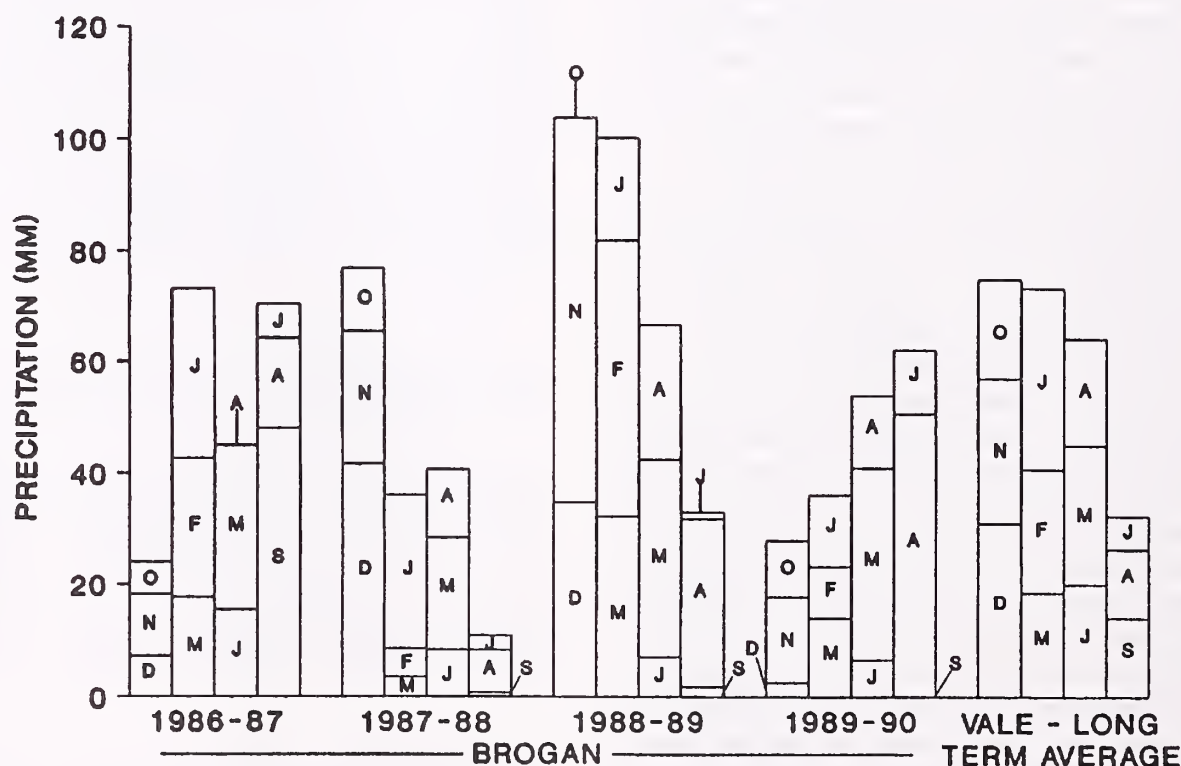

Figure 1—Monthly precipitation, Brogan, OR, October 1986 through September 1990 (author's data) and long-term mean monthly precipitation, Vale, OR (USDC 1986 to 1990).
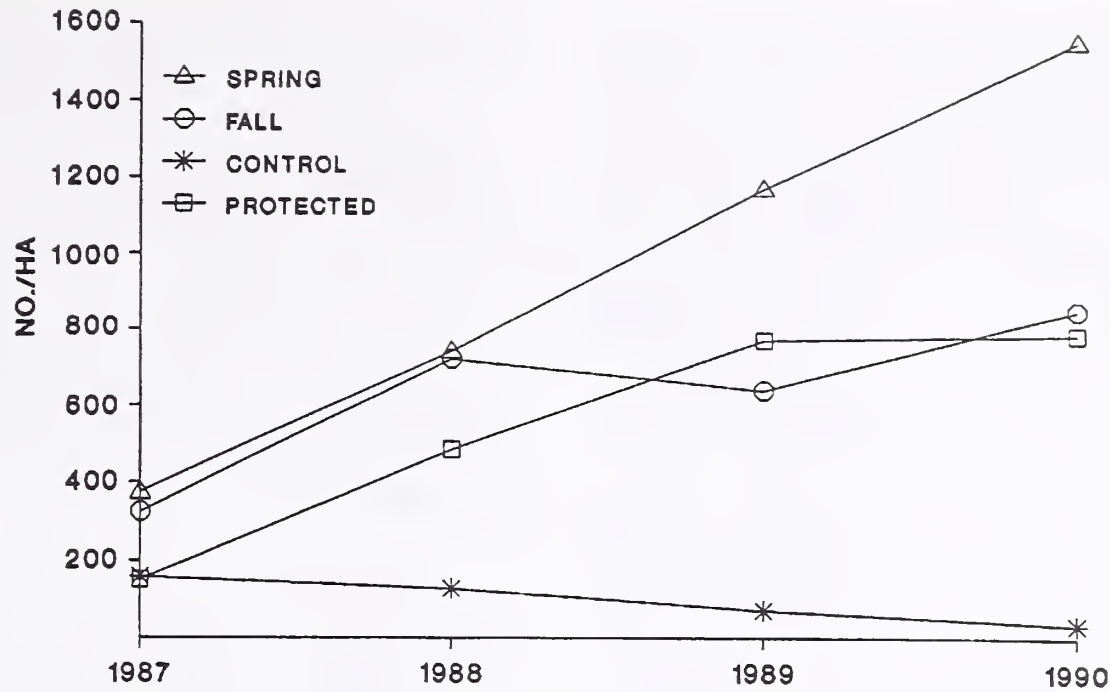
Figure 2—Sandbar willow seedling density by treatment, 1987 to 1990, Pole Creek Experimental Pastures.
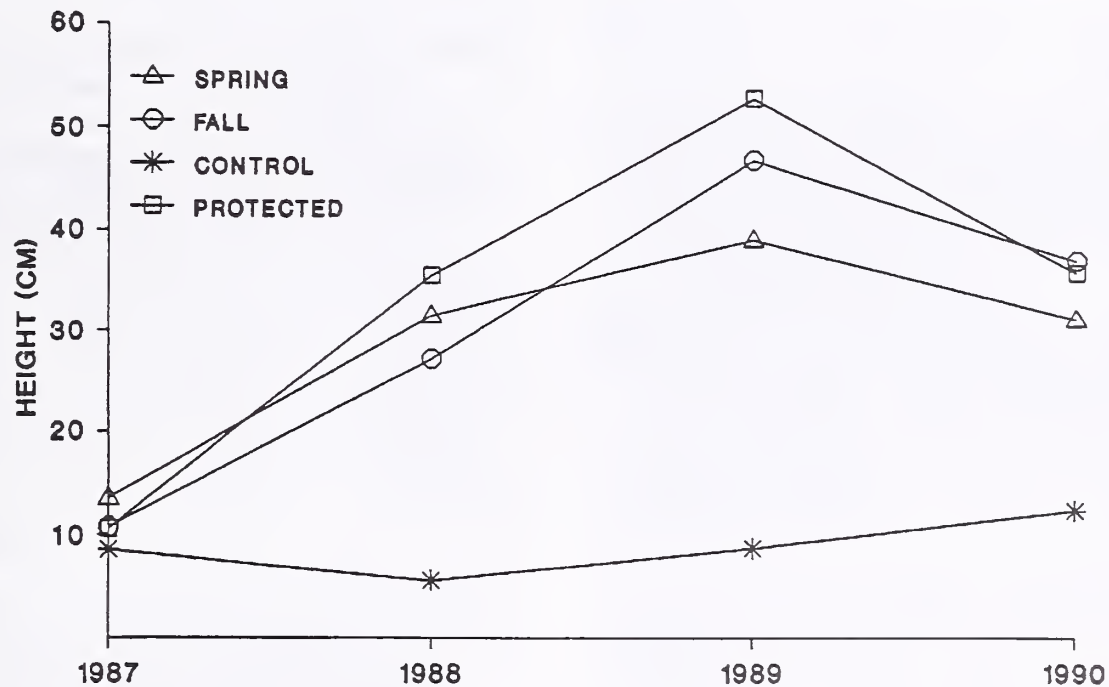

Figure 3—Sandbar willow seedling height by treatment, 1987 to 1990, Pole Creek Experimental Pastures.

Sediment deposits and burial of some seedlings by a flash flood just prior to sampling in 1990 may have affected measurements. In 1990 mean height of each species did not exceed 50 cm for any treatment due to heavy browsing by deer in protected pastures and deer and livestock in reduced-grazing pastures. Until seedling height exceeds 150 to 170 cm, available forage is entirely within reach of grazing animals; the ability of seedlings to survive to maturity is uncertain. In 1990, fewer than 5 percent of the willow seedlings in restricted grazing pastures exceeded 100 cm in height (table 2). All seedlings in control pastures were less than 50 cm tall.

Crown development on seedlings of both willow species has also been severely limited by cattle and wildlife use (table 3). Lateral spread by new shoots has been almost nonexistent. By 1990 Pacific willow seedlings averaged only 1.6 and sandbar willow 1.2 basal stems, with no significant differences among treatments. Treatments did impact crown diameter. Mean crown diameter of Pacific willow and sandbar willow seedlings under reduced grazing treatments was 130 and 66 percent greater than respective controls.
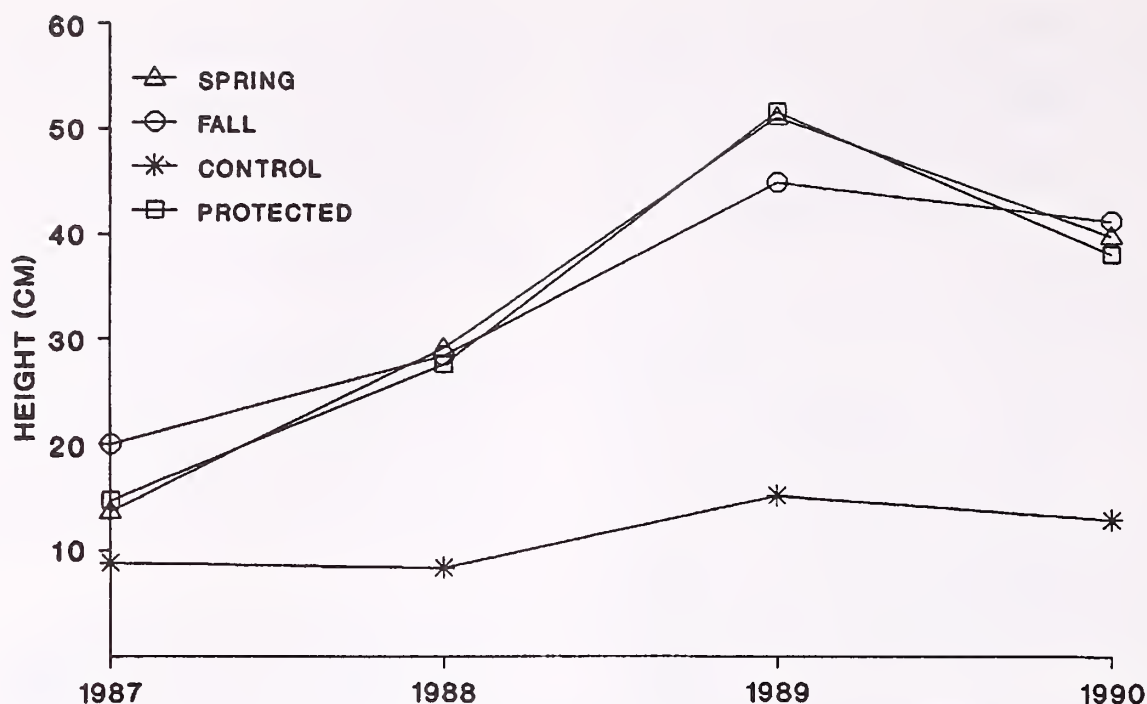
Figure 4—Pacific willow seedling height by treatment, 1987 to 1990, Pole Creek Experimental Pastures.

DISCUSSION

Pacific willow and sandbar willow are common along streambanks and quickly invade disturbed areas. Seeds are likely transported by wind and water from plants higher on the watershed or by wind from downstream plants. Offsite plants can be important seed sources (Uchytil 1989a, b). Very few seed-bearing willows occurred within the 5-km section of Pole Creek that includes the experimental pastures. However, new seedlings were observed each year in pastures with reduced grazing treatments. By 1990, average willow seedling density in these pastures was 2,054/ha of stream-affected vegetation, significantly exceeding the 212 seedlings/ha mean for control pastures that were grazed with the surrounding allotment.

Zasada (1986) commented that establishment of woody species on disturbed sites is related to stochastic events and availability of suitable microsites for germination and establishment. Seeds of Pacific willow and sandbar willow can be transported for considerable distances, but remain viable for only a short period, perhaps only 1 week. Moist mineral soils and light are required for germination (Hansen and others 1988a). Only those seeds that quickly encounter fresh sediment deposits or other saturated soil surfaces exposed to light and free of dense competing vegetation have an opportunity to germinate and establish. Consequently, germination and establishment are related to effects of grazing treatments on availability of suitable microsites as well as season and intensity of use of willow seedlings and competing vegetation. Variability in seed production from year to year, drought conditions, erratic summer flood events, and inherent differences in microsite availability within and between pastures with the

Table 2—Height distribution of Pacific and sandbar willows by grazing treatment, October 1990, Pole Creek Experimental Pastures

Species	Grazing treatment			
Height class	Spring	Fall	Protected	Control
	----------- Percent -----------			
Salix lasiandra				
≤50 cm	73.0	68.8	70.4	100
51-100 cm	23.5	31.2	28.3	—
101-150 cm	3.4	—	1.3	—
Salix exigua				
≤50 cm	86.0	81.2	82.4	100
51-100 cm	13.3	17.5	15.8	—
101-150 cm	0.6	1.3	1.8	—

Table 3—Mean number of basal stems and mean crown diameters of Pacific willow and sandbar willow seedlings by grazing treatment, October 1990, Pole Creek Experimental Pastures

Grazing treatment	*Salix lasiandra*		*Salix exigua*	
	Basal stems	Crown diameter	Basal stems	Crown diameter
	No.	cm	No.	cm
Spring	1.7	[1]28.0a	1.5	18.2a
Fall	1.6	28.1a	1.5	21.8a
Protected	1.4	26.0a	1.5	22.3a
Control	1.5	11.9b	1.0	12.5b

[1]Within columns, means followed by the same letter do not differ ($p < 0.05$).

134

same grazing treatment are among factors not quantified in this study that may have had major impacts on willow seed and seedling distribution and survival.

Heavy browsing to this point has severely restricted vertical development as well as lateral spread of willow seedlings. Those few willows within the watershed that have grown out of reach of browsing animals rapidly develop spreading crowns, but new sprouts continue to be removed at ground level. Vertical and lateral development create bands of dense, well-rooted plants that bind the streambank, trap sediment, and improve physical characteristics of the stream and its associated riparian area, and provide habitat critical for improving faunal diversity along the stream and within the surrounding watershed (Finch 1987; Lindauer 1983; Thomas and others 1979).

Very little is known about the relative palatability of Pacific willow, sandbar willow, or their subspecies. Kufeld and others (1973) and Van Dersal (1938) reported that Pacific willow is highly palatable to mule deer in summer, but receives little use in winter. Sampson and Jesperson (1963) considered it to be of little value to livestock in California. However, Hansen and others (1988b) reported loss of vigor and plants from excessive use of Pacific willow by livestock in Montana. Van Dersal (1938) described sandbar willow as highly palatable to livestock, but not deer. Both willow species receive heavy use by elk and beaver (Gaffney 1941; Kindschy 1985; Kufeld 1973; Mozingo 1987; Patten 1968).

Browsing of both willow species was extremely heavy in all pastures along Pole Creek due to the extremely degraded condition of riparian areas along the stream, drought conditions prevailing throughout much of the study period, and the resulting scarcity of succulent vegetation. Consequently, differences in deer and cattle preference for the two species have not been distinguished. Additional years of study are required to determine whether willow seedlings of either species are capable of growing out of reach of browsing animals and develop normal growth habits.

CONCLUSIONS

Although there were almost no mature willows within the Pole Creek study area, seed dispersal from offsite plants was adequate to provide reasonable seedling densities of both Pacific willow and sandbar willow in all but the control pastures. Thus, disturbed riparian sites, particularly those that are heavily grazed, should be examined carefully for presence of new seedlings to determine whether the areas may recover naturally or whether artificial revegetation may be required.

After 4 years of treatment, density and growth of willow seedlings were greater in pastures with spring or fall grazing or protected from cattle grazing compared to season-long grazing (control) pastures. A similar pattern has been observed with respect to condition of streamside herbaceous communities and physical characteristics of the stream channel (Clary 1991).

Additional time will be required to allow full expression of any differences in response of willow seedlings to applied grazing treatments at Pole Creek and to determine whether willows subjected to any of these treatments are capable of growing beyond the reach of livestock and wildlife. Flash floods have seriously impacted seedling establishment and survival. The study pastures are small and subject to concentrated wildlife use. However, they are comparable in area to many riparian improvement projects, planting sites, and demonstration areas. Alterations in management plans at the watershed level may be necessary to dilute wildlife impacts and enhance rapid recovery of woody riparian species.

REFERENCES

Argus, George W. 1973. The genus *Salix* in Alaska and the Yukon. Publications in Botany, No. 2. Ottawa, ON: National Museums of Canada, National Museum of Natural Sciences. 279 p.

Brunsfeld, Steven J.; Johnson, Frederic D. 1985. Field guide to the willows of east-central Idaho. Bull. 39. Moscow, ID: University of Idaho, College of Forestry, Wildlife and Range Sciences, Forest, Wildlife and Range Experiment Station. 82 p.

Clary, Warren P. 1987. Livestock effects on riparian vegetation and adjoining streambanks. Study Plan 4202-1-3. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, Boise, ID. 22 p. + appendices.

Clary, Warren P. 1989. Brief review of vegetation plot results on Pole Creek and Willow Creek. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, Boise, ID. n.p.

Clary, Warren P. 1990. Differences in vegetation biomass and structure due to cattle grazing in a northern Nevada riparian ecosystem. Res. Pap. INT-427. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 8 p.

Clary, Warren P. 1991. Brief summary of 1990 general vegetation and stream channel results, Pole Creek, OR. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, Boise, ID. n.p.

Crouse, M. R.; Kindschy, R. R. 1984. A method for predicting riparian vegetation potential of semi-arid rangelands. In: Proceedings; 1984 Pacific Northwest range management short course; range watersheds, riparian zones, and economics: interrelationships in management and use; Corvallis, OR. Corvallis, OR: Oregon State University. 83 p.

Dorn, Robert D. 1977. Willows of the Rocky Mountain States. Rhodora. 79: 390-429.

Finch, Deborah M. 1987. Bird-habitat relationships in subalpine riparian shrublands of the central Rocky Mountains. In: Troendle, Charles A.; Kaufmann, Merrill R.; Hamre, R. H.; Winokur, Robert P., tech. coords. Management of subalpine forests: building on 50 years of research: Proceedings of a technical conference; 1987 July 6-9; Silver Creek, CO. Gen. Tech. Rep. RM-149. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 167-172.

Gaffney, W. S. 1941. The effects of winter elk browsing, South Fork of the Flathead River, Montana. Journal of Wildlife Management. 5: 427-453.

Haeussler, S.; Coates, D. 1986. Autecological characteristics of selected species that compete with conifers in British Columbia: a literature review. Victoria, BC: Canadian Ministry of Forests, Information Services Branch. 180 p.

Hansen, Paul L.; Chadde, Steve W.; Pfister, Robert D. 1988a. Riparian dominance types of Montana. Misc. Publ. 49. Missoula, MT: University of Montana, School of Forestry, Montana Forest and Conservation Experiment Station. 411 p.

Hansen, Paul L.; Chadde, Steve; Pfister, Robert; [and others]. 1988b. Riparian site types, habitat types, and community types of southwestern Montana. Missoula, MT: University of Montana, School of Forestry, Montana Riparian Association. 140 p.

Kauffman, J. Boone; Krueger, W. C. 1984. Livestock impacts on riparian ecosystems and streamside management implications...a review. Journal of Range Management. 37: 430-437.

Kauffman, J. Boone; Krueger, W. C.; Vavra, M. 1983a. Effects of late season cattle grazing on riparian plant communities. Journal of Range Management. 36: 685-691.

Kauffman, J. Boone; Krueger, W. C.; Vavra, M. 1983b. Impacts of cattle on streambanks in northeastern Oregon. Journal of Range Management. 36: 683-685.

Kindschy, Robert R. 1985. Response of red willow (*Salix lasiandra*) to beaver use in southeastern Oregon, USA. Journal of Wildlife Management. 49: 26-28.

Kufeld, Roland C. 1973. Foods eaten by the Rocky Mountain elk. Journal of Range Management. 26: 106-113.

Kufeld, Roland C.; Wallmo, O. C.; Feddema, Charles. 1973. Foods of the Rocky Mountain mule deer. Res. Pap. RM-111. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 31 p.

Lindauer, Ivo E. 1983. A comparison of the plant communities of the North Platte and Arkansas River drainages in eastern Colorado. The Southwestern Naturalist. 28: 249-259.

Marlow, Clayton B.; Olson-Rutz, Kathrin; Atchley, Jennifer. 1989. Response of a southwest Montana riparian system to four grazing management alternatives. In: Gresswell, Robert E.; Barton, Bruce A.; Kershner, Jeffrey L., eds. Practical approaches to riparian resource management—an educational workshop; 1989 May 8-11; Billings, MT. Billings, MT: U.S. Department of the Interior, Bureau of Land Management: 111-116.

Mozingo, Hugh N. 1987. Shrubs of the Great Basin: a natural history. Reno, NV: University of Nevada Press. 342 p.

Patten, D. T. 1968. Dynamics of the shrub continuum along the Gallatin River in Yellowstone National Park. Ecology. 49: 1107-1112.

Patton, D. R. 1977. Riparian research needs. In: Johnson, R. R.; Jones, D. A., tech. coords. Importance, preservation and management of riparian habitat: a symposium. Gen. Tech. Rep. RM-43. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 80-82.

Platts, William S.; Armour, Carl; Booth, Gordon D.; [and others]. 1987. Methods for evaluating riparian habitats with applications to management. Gen. Tech. Rep. INT-221. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 177 p.

Sampson, Arthur W.; Jespersen, Beryl S. 1963. California range brushlands and browse plants. Berkeley, CA: University of California, Division of Agricultural Sciences, California Agricultural Experiment Station, Extension Service. 162 p.

Skovlin, Jon M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In: Natural Research Council/National Academy of Sciences. Developing strategies for rangeland management. Boulder, CO: Westview Press: 1001-1103.

Stephens, H. A. 1973. Woody plants of the North Central Plains. Lawrence, KS: The University Press of Kansas. 530 p.

Thomas, Jack Ward; Maser, Chris; Rodiek, Jon E. 1979. Wildlife habitats in managed rangelands—the Great Basin of southeastern Oregon, riparian zones. Gen. Tech. Rep. PNW-80. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 18 p.

Uchytil, Ronald J. 1989a. *Salix exigua*. In: Fischer, William C., compiler. The Fire Effects Information System [Data base]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory. Magnetic tape reels; 9 track; 1600 bpi, ASCII with Common LISP present.

Uchytil, Ronald J. 1989b. *Salix lasiandra*. In: Fischer, William C., compiler. The Fire Effects Information System [Data base]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory. Magnetic tape reels; 9 track; 1600 bpi, ASCII with Common LISP present.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration. 1986-1990. Climatological data Oregon. Asheville, NC: National Climatic Data Center. Vols. 92-96. n.p.

U.S. Department of the Interior, Bureau of Land Management, Vale District. 1982. Poall Creek allotment management plan 0103. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, Boise, ID. n.p.

U.S. Department of the Interior, Bureau of Land Management, Vale District. 1987. Poall Creek allotment evaluation. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, Boise, ID. 3 p.

Van Dersal, William R. 1938. Native woody plants of the United States, their erosion-control and wildlife values. Washington, DC: U.S. Department of Agriculture. 362 p.

Van Haveren, B. P.; Jackson, W. L. 1986. Concepts in stream riparian rehabilitation. In: Transactions of the 51st North American Wildlife and Natural Resources Conference: 280-289.

Youngblood, Andrew P.; Padgett, Wayne G.; Winward, Alma H. 1985. Riparian community type classification of eastern Idaho-western Wyoming. R4-Ecol-85-01. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 78 p.

Zasada, J. 1986. Natural regeneration of trees and tall shrubs on forest sites in interior Alaska. In: Van Cleve, K.; Chapin, F. S., III; Flanagan, P. W.; [and others], eds. Forest ecosystems in the Alaska taiga: a synthesis of structure and function. New York: Springer-Verlag: 44-73.

ROOTING HARDWOOD CUTTINGS OF SITKA AND THINLEAF ALDER

Bonita J. Java
Richard L. Everett

ABSTRACT

Rooting abilities of woody cuttings of Sitka (Alnus sinuata) *and thinleaf* (A. incana ssp. tenuifolia) *alder were evaluated after cold storage and growth regulator [indolebutyric acid (IBA), naphthaleneacetic acid (NAA)] treatments. Leaves flushed on Sitka alder cuttings, but no cuttings rooted in response to cold or growth regulator treatments. A maximum number of thinleaf cuttings rooted (76 percent) when the basal end was treated with a concentrated solution of 2,000 ppm IBA/1,000 ppm NAA and placed in cold storage at 1 to 3 °C for 1 month. Untreated thinleaf cuttings had a rooting success of 11 percent.*

INTRODUCTION

Planting N-fixing species to restore degraded forest soils has been a silviculture practice for more than a century in Europe (Mikola and others 1983) and for several decades in New Zealand and North America (Tarrant 1983). Alder, a pioneer species, has widely accepted value as a soil-N and humus-building plant (Heilman and Ekuan 1982). Thinleaf alder (*Alnus incana* [L.] Moench ssp. *tenuifolia* [Nutt.] Breit. [*A. tenuifolia*]) and Sitka alder (*A. sinuata*) are both native to the eastern slopes of the Cascade Mountain Range on the North American Continent. Although these species have little commercial wood value, they may play a role in increasing site productivity for associated conifers (Tarrant 1968). Thinleaf alder grows in riparian areas, has potential for stabilizing streambanks, and provides shade that may contribute to fish habitat (Monsen, in preparation). Information is needed on propagation of these species before they can be fully utilized in the restoration of forest soils and wildlife habitat. Specifically, we needed a rapid propagation procedure (6 months or less) that would provide a plant with a woody base resistant to trampling and harsh climatic conditions on high-elevation riparian sites.

Few studies have been done on rooting hardwood alder cuttings. Rooting success can be nearly 100 percent with 5-week-old shoots of *A. incana* (Huss-Danell and others 1980), but Holloway and Zasada (1979) reported no rooting success for hardwood cuttings. Carpenter and others (1984) successfully rooted new green stem cuttings of

Sitka alder, but we found no record in the literature for rooting hardwood cuttings. Kralik and Sebanek (1981), Robison and Hall (1983), and Psota and others (1986) suggest dormancy requirements must be met before rooting will occur on alder cuttings. Cold storage of cuttings has been used to break dormancy, but storage for more than a month may reduce rooting potential (Macdonald 1986).

Standard horticultural practices utilize growth regulators (indolebutyric acid, indoleacetic acid, or naphthaleneacetic acid) to break dormancy and initiate callus formation for root growth (Hartmann and Kester 1975; Macdonald 1986). These authors also describe two methods of solution growth regulator application: the concentrated solution dip method and the 24-hour dilute solution soak method. In this study we evaluated root and shoot growth responses of thinleaf and Sitka alder cuttings to concentrated and dilute growth regulator treatments, with and without cold storage.

METHODS

The stems of 20 thinleaf and 20 Sitka alder plants were harvested in January at 2,200 ft (671 m) and 3,700 ft (1,128 m) elevation on Stevens and Blewett Passes, respectively, in north-central Washington. Plant material was transported to the laboratory and held in water overnight. Terminal stems were recut under water into 6- to 10-cm cuttings with basal diameters of 3 to 5 mm.

Two main treatments were applied to cuttings: (1) cold storage to test if dormancy was a factor controlling rooting, and (2) application of growth regulators to improve rooting percent and growth. Control treatments of cuttings not placed in cold storage or treated with growth regulators were included in the study. The basal ends (2 cm) of the cuttings treated with growth regulator were subjected to a 10-second emersion in concentrated IBA/NAA growth regulator solutions or a 24-hour soak in dilute IBA/NAA growth regulator solutions prior to planting or cold storage. Concentrated growth regulator solutions used in the quick-dip were 10,000 ppm IBA/5,000 ppm NAA; 8,000 ppm IBA/4,000 ppm NAA; 4,000 ppm IBA/2,000 ppm NAA; and 2,000 ppm IBA/1,000 ppm NAA. Growth regulator solutions used in the 24-hour soak were 100 ppm IBA/50 ppm NAA; 50 ppm IBA/25 ppm NAA; and 25 ppm IBA/12.5 ppm NAA. Twenty cuttings, one from each of the 20 plants, were used as a replicate, with four replicates to test individual treatment effects for each alder species.

After application of growth regulators, one-half of the cuttings were placed in cold storage at 1 to 3 °C for 1 month and the remaining cuttings were inserted into the

---

rooting medium immediately. Cuttings were inserted one per individual 2- by 2- by 6-inch plant container filled with a 1:2 peat and perlite mix. Cold-stored cuttings were sealed in plastic to prevent dehydration, stored 30 days at 1 to 3 °C, and then inserted one per plant container.

Plant containers holding cuttings were placed on greenhouse mist benches that received 1 minute of spray every half hour. Greenhouse temperatures fluctuated from 68 to 90 °F with soil temperatures ranging from 58 to 60 °F. A 63 percent shadecloth was put over the greenhouse in mid-February when outside temperatures and light intensity became so high that greenhouse temperatures could not be stabilized at below 85 °F. Fluorescent lighting (13 microeinsteins, m²/sec) was provided to maintain a constant photoperiod to 16 hours per day.

Cuttings were randomized across the mist bench weekly to reduce any confounding microclimate effects. Beginning 1 month after planting, cuttings were fertilized weekly with a 50-ppm solution (20-20-20 NPK) for 3 weeks; on the fourth week a 50-ppm solution (23-19-17 NPK) with micronutrients was applied. Fungicide (Benomyl) was applied as a topical spray in mid-March when bud and leaf drop were observed. In the twelfth week following planting, cuttings were inoculated with a soil/water slurry taken from around the roots of alder plants at the harvest sites, and fertilizer treatments were held for a 2-week period. Cuttings were evaluated for top and root growth after cold-stored cuttings had been under the mist system for 17 weeks and nonstored cuttings for 21 weeks.

DATA COLLECTION AND ANALYSIS

Data were collected describing shoot growth (leaf area, number of leaves, original and final stem length) and root growth (percent cuttings rooted, maximum root length, and root numbers). Root numbers and root length were recorded from the observable roots on the outside of the root-soil mass prior to preparation of cuttings for outplanting in a subsequent study.

Data were analyzed by analysis of variance followed by orthogonal contrast tests among treatments (Little and Hills 1978). Orthogonal contrasts queried the data for significant differences among cold storage vs. noncold treatment, between quick-dip vs. soak treatments, and among concentrations of growth regulators and possible interaction effects at the $p = 0.05$, 0.1 levels.

RESULTS

Cutting age and size were similar between Sitka and thinleaf cuttings. No cuttings of Sitka alder rooted, although bud burst and leaf growth occurred. The following discussion relates to thinleaf alder only. Maximum rooting for thinleaf alder was 76 percent, obtained using concentrated 2,000 ppm IBA/1,000 ppm NAA growth-regulator solutions in combination with cold storage. Only 11 percent of the thinleaf alder cuttings rooted if not subjected to either cold storage or growth regulator treatments (controls).

Cold storage and growth regulator treatments were effective in stimulating rooting (table 1), with cold storage increasing rooting of the cuttings to a greater extent than growth regulator treatments. Growth regulator treatments combined with cold storage produced more roots of greater lengths than the cold treatment alone. However, the combination of treatments did not significantly increase the percentage of cuttings that rooted over the rooting success achieved with cold storage alone. The

Table 1—Root and top growth of thinleaf alder cuttings

Growth regulator concen- tration	Cold storage								No cold storage							
	Concentrated dip (ppm)				Dilute soak (ppm)				Concentrated dip (ppm)				Dilute soak (ppm)			
	10,000	8,000	4,000	2,000	100	50	25	0	10,000	8,000	4,000	2,000	100	50	25	0
Root growth Percent rooted	[1]64	71	73	76	64	66	65	64	24	22	23	15	33	18	22	11
Number (rep)	50	46	40	38	48	36	30	28	16	12	10	8	28	12	12	8
Length (cm)	11	11	10	11	9	9	8	7	4	4	3	3	5	4	4	2
Top growth Leaf area (cm²)	14	14	12	10	15	12	10	6	4	4	3	3	4	4	4	2
Leaf No.	33	30	28	29	28	23	22	17	12	14	8	8	15	9	11	6
Shoot growth (cm)	5.8	5.7	4.5	4.8	7.6	5.5	4.5	2.5	1.8	1.6	1.3	1.4	2.2	1.8	1.5	1.2

[1]Underline denotes treatments not significantly different ($p = 0.05$) from the maximum.

Table 2—Orthogonal contrasts among treatment means

Treatments	Root growth			Top growth		
	Rooted	Number	Length	Leaf area	Leaf number	Shoot growth
	Percent	No.	cm	cm²	No.	cm
Cold vs. no cold	[1]68-27	[1]36-12	[1]9-3	[1]10-3	[1]24-10	[2]5-2
Cold						
Treated vs. control	70-64	[1]41-36	[1]10-7	[1]13-10	[1]27-24	[2]5-3
Concentrate vs. dilute	[2]74-65	44-37	[1]11-9	13-12	[1]30-24	5-6
No cold						
Treated vs. contro	23-11	15-8	[2]4-2	4-2	13-6	2-2
Concentrate vs. dilute	21-25	12-17	4-4	4-4	11-12	2-2

[1,2]Significant difference at $p = 0.05$, 0.1 probability levels.

concentrated dip application method produced significantly longer roots ($p = 0.05$) than the 24-hour soak treatment for cold-stored cuttings. Root number increased with increasing concentration of growth regulator for soak plus cold-treated cuttings. Growth regulator increased root length only on cold-stored cuttings.

There was a significant interaction between growth regulator application methods and cold treatment for rooting percentage and root length. Rooting percentage and root length declined from concentrated dip to dilute soak treatments for cold-stored cuttings (table 2).

Cold-stored cuttings (except controls) had significantly greater leaf area, leaf numbers, and shoot growth than cuttings not treated with cold storage (tables 1 and 2). The combination of cold and growth regulators produced significantly more leaves, leaf area, and stem growth than the cold treatment alone. Leaf area increased with concentration of growth regulator in concentrated dip and dilute soak application treatments for cold-stored cuttings ($p = 0.1$). Shoot growth increased with concentration of growth regulator in concentrated dip and dilute soak solutions for both cold-stored and and nonstored cuttings.

SUMMARY

Cold storage and root growth regulators enhanced rooting of winter hardwood cuttings of thinleaf alder. Although Sitka alder cuttings burst buds and put on new leaves, we could not root Sitka alder cuttings with any treatment. Both the dilute 24-hour soak method and the concentrated dip method of applying growth regulators increased rooting and top growth of thinleaf alder. Maximum rooting success for thinleaf alder was 76 percent, and occurred when cuttings were treated with 2,000 ppm IBA and 1,000 ppm NAA solution followed by 1-month cold storage at 1 to 3 °C before planting. Cold storage was more effective at increasing rooting over untreated cuttings (64 compared to 11 percent) than root-growth regulator treatments (32 compared to 11 percent). There was no significant difference in percent rooting between

growth-regulator-treated and untreated controls in cold-stored cuttings. Cold-stored cuttings had greater rooting percent and longer roots than nonstored cuttings that were placed in the rooting medium 1 month prior to the stored cuttings.

Our higher IBA concentrations, added NAA, and shorter cold storage time may explain increased rooting success over that reported by Holloway and Zasada (1979). The absence of bottom heat for our cuttings may explain our failure to successfully root Sitka alder as reported by Carpenter and others (1984).

The winter collection of thinleaf alder cuttings and their subsequent rooting provided planting stock for outplanting at moist, high-elevation sites by midsummer. Sitka alder transplants that we had grown from seed during the rooting study had much weaker stems and were more difficult to transplant onto field sites.

ACKNOWLEDGMENTS

REFERENCES

Carpenter, C. V.; Robertson, L. A.; Gordon, J. C.; Perry, D. A. 1984. The effect of four new *Frankia* isolates on growth and nitrogenase activity in clones of *Alnus rubra* and *Alnus sinuata*. Canadian Journal of Forest Research. 14: 701-706.

Haeussler, S.; Coates, D. 1986. Autecological characteristics of selected species that compete with conifers in British Columbia: a literature review. Victoria, BC: Province of British Columbia, Information Services Branch, Ministry of Forests: 18-21.

Hartmann, Hudson T.; Kester, Dale E. 1975. Plant propagation: principles and practices. Vol. 1. Englewood Cliffs, NJ: Prentice-Hall. 662 p.

Heilman, P.; Ekuan, G. 1982. Nodulation and nitrogen fixation by red alder and Sitka alder on coal mine spoils. Canadian Journal of Forest Research. 12: 992-997.

Holloway, P.; Zasada, J. 1979. Vegetative propagation of 11 common Alaska woody plants. Res. Note PNW-334. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 12 p.

Huss-Danell, K.; Eliasson, L.; Ohberg, I. 1980. Conditions for rooting of leafy cuttings of *Alnus incana*. Physiology Plantarum. 49: 113-116.

Kralik, J.; Sebanek, J. 1981. A contribution to the study on the onset of endogenous dormancy in some decorative coniferous and deciduous woody species. Brno, Czechoslovakia: Institute of Experimental Phytotechnics. Acta Universitatis Agriculturae Brno, A (Facultas Agronomica). 29: 55-64.

Little, T. M.; Hills, F. J. 1978. Agricultural experimentation: design and analysis. New York: John Wiley & Sons. 350 p.

Macdonald, Bruce. 1986. Practical woody plant propagation for nursery growers. Vol. 1. Portland, OR: Timber Press. 669 p.

Mikola, P.; Uomala, P.; Malkonen, E. 1983. Application of biological nitrogen fixation in European silviculture. In: Gordon, J.; Wheeler, C.,eds. Biological nitrogen fixation in forest ecosystems: foundations and applications. Boston, MA: Martinus Nijhoff/Dr. W. Junk, Publishers: 279-294.

Monsen, Stephen B.; Stevens, Richard; Shaw, Nancy L. [In preparation]. Shrubs of other families. In: Monsen, S. B.; Stevens, R., eds. Rehabilitation of western range and wildlands. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Psota, V.; Kralik, J.; Ondrackova, O.; Sebanek, J. 1986. Effect of cyclophysis of the level of endogenous gibberellins and selected plant growth regulators on rhizogenesis in common alder (*Alnus glutinosa* (L.) Gaertn.). Brno, Czechoslovakia: Institute of Experimental Phytotechnics. Acta Universitatis Agriculturae Brno, A (FacultasAgronomica). 34: 7-23.

Robison, T. L.; Hall, R. B. 1983. Approaches to European alder improvement . In: Guries, R. P., ed. Proceedings of the second North Central tree improvement conference; 1981 August 5-7; Lincoln, NE. Ames, IA: Iowa State University, Department of Forestry; Madison, WI: University of Wisconsin, Department of Forestry: 65-77.

Schopmeyer, C. S. 1974. Seeds of woody plants in the United States. Agric. Handb. 450. Washington, DC: U.S. Department of Agriculture, Forest Service. 883 p.

Tarrant, Robert F. 1968. Some effects of alder on the forest environment. In: Trappe, J. M.; Franklin, J. F.; Tarrant, R. F.; Hansen, G. M., eds. Biology of alder. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 193-194.

Tarrant, R. 1983. Nitrogen fixation in North American forestry: research and application. In: Gordon, J.; Wheeler, C., eds. Biological nitrogen fixation in forest ecosystems: foundations and applications. Boston, MA: Martinus Nijhoff/Dr. W. Junk, Publishers: 261-277.

SEED GERMINATION DATA FOR YELLOW WILLOW AT A NEVADA RIPARIAN SITE

Ellen Martens
James A. Young

ABSTRACT

*Ease of vegetative propagation and the reputation that the seeds have a very short storage life has resulted in seed and seedling ecology of the willows largely being ignored. Seeds of yellow willow (*Salix lutea *[Bebb] Jeps.) were collected from riparian areas along the eastern flank of the Sierra Nevada. Freshly collected seeds were germinable at a range of incubation temperatures from 5 through 30 °C. Seeds remained viable at room temperatures for 7 weeks.*

INTRODUCTION

Seeds of willow species have been considered to be recalcitrant (not desiccating at maturity) and therefore having a very short period of viability after maturity. The general silvicultural recommendation has been to sow willow seeds as soon after collection as possible (Brinkman 1974). It is apparently not known how important sexual versus vegetative reproduction is in recruitment of new individuals in riparian habitats in Western North America.

Our purpose was to gain preliminary data on the basic seed development, maturity, harvesting, and germination of seeds of a common willow species.

METHODS

Phenological observations of willow seed development were made on flowering stands of yellow willow (*Salix lutea* [Bebb] Jeps.) along the Truckee River west of Reno, NV, in 1989 and 1990. We determined that it was very difficult to time the collection of seeds during the dispersal period. It proved more practical to make cuttings bearing inflorescence and transport them to a warm laboratory bench. The mature capsules rapidly opened, releasing the seeds.

Seeds from 10 sources of yellow willow were placed in dark incubators, in petri dishes on one layer of germination paper, and kept moist with tap water. Four replications of 25 seeds each were tested from each source. Seeds were considered germinated when the radicle was visible. Germination counts were made after 1, 2, and 4 weeks incubation. Initial incubation temperatures were 2 °C, and

5 through 40 °C in 5 °C increments. Based on the results of this initial experiment, seeds were incubated at 0, 2, 5, and at 5 °C increments through 40 °C and at alternating temperature regimes consisting of 16 hours at each constant temperature and 8 hours at each higher temperature daily. For example, 0 °C alternated with 2, 5, 10, 15, 20, 25, 30, 35, and 40 °C, but 35 °C alternated with 40 °C only (Young and Evans 1982).

The germination observed for the 55 constant or alternating temperature combinations in the germination profile was categorized in comparison to seedbed temperatures for the Great Basin during the spring germination period (Evans and others 1970). The categories of seedbed temperatures are: very cold, 0/0 through 0/5 °C and 2/2 °C; cold, 0/10, 0/15, 2/5 through 2/15, 5/5 and 5/10 °C; cold fluctuating, 2/20 through 2/40 and 5/20 through 5/40 °C; moderate, 5/15 through 5/25, 10/10 through 10/30, 15/15 through 15/35, 20/20 through 20/35, and 25/25 and 25/30 °C; warm fluctuating, 5/30 through 5/40, 10/35 and 10/40, and 15/40 °C; and warm, 20/40, 25/35, 25/40, 30/30 through 30/40, 35/35, 35/40, and 40/40 °C.

Yellow willow seeds were stored for 7 weeks in the following environments: (a) in paper bags in the laboratory at room temperature, (b) in paper bags at 0 °C, (c) in water at 2 °C, and (d) in a desiccator over $CaCl_2$ at 0 °C (approximate relative humidity 2.4 percent). At the end of storage the seeds were incubated as above at 20 °C and germinated seeds counted.

The experimental design consisted of a four-replication random block with 25 seeds/petri dish. Least-squares multiple regression techniques were employed to test effects of temperature on germination rate. Some analyses utilized a quadratic regression equation and others had best fit with the cubic form. Estimated percent germination values and their corresponding confidence intervals were derived from the equations. These confidence intervals were used as the posthoc multiple comparison procedure to statistically separate germination differences.

RESULTS

Along the trans-Sierra, willows are perhaps the first woody dicot to bloom in riparian habitats. The date of catkin appearance appears highly variable among yellow willow plants of the same apparent species. A clump of yellow willows in northwestern Reno was consistently a month earlier than the majority of plants in the area. The male and female flowers do not occur in the same catkin and usually are borne on separate plants. Usually the catkins appear before the majority of the leaf buds break

dormancy. Sepals and petals are completely lacking in willow flowers, but each flower is usually subtended by small scales. Glands on the petioles secrete nectar that attracts insect pollinators. The glands also attract jumping plant lice (Psyllidae) that make seed collecting messy and threshing difficult. The plant lice are harmless to humans and do not directly influence seed quality, but when very abundant they present a problem in seed handling and make willow seed collectors unpopular with their associates.

The first catkins appear in late March or early April and the fruit, a conic-ovoid capsule, nears maturity within a month. The flowers within a catkin are indeterminate, and catkins upon a branch vary considerably in phenology. When the majority of the catkins contain capsules that appear ready to burst cuttings should be made and taken into a warm room. When the capsules of yellow willow are about ready to burst the silky hairs that coat the seeds are starting to become visible.

The seed coat is not visible when the capsule splits because of the dense covering of silky hairs on the seeds. The seeds are dispersed by wind, but they also readily float on water and apparently remain buoyant for prolonged periods. The seeds themselves are only about 1 mm long, less than 0.5 mm in diameter, and their average weight is 8 seeds per milligram. Brinkman (1974) gives a range of seed weights for willow seeds from 1 to 25 per milligram depending on the species. The hairs on the seed coat obviously aid in dispersal, but they may serve other functions during the germination and initial seedling establishment. For this reason and the fact that the seeds are very fragile, the hairs should not be removed.

Germination at Constant Temperatures

Tests on 10 sources of yellow willow seed showed germination was highest at 10 through 25 °C incubation temperatures (fig. 1). Over 10 percent germination at 2 °C incubation temperatures indicates the capacity to germinate at very low incubation temperatures. Only incubation at 35 and 40 °C failed to produce any germination.

Germination Profile

Percentage germination at constant incubation temperatures for one source of yellow willow seeds (table 1) was lower than was observed in previous repeated constant incubation tests (fig. 1). Maximum germination at constant 10 through 25 °C incubation temperatures was only 34 percent. At a fluctuating 2/10 °C (2 °C for 16 hours and 10 °C for 8 hours in each 24 hours) the maximum germination for the profile occurred at 52 percent. Germination was inhibited only at 40 °C.

Comparison to Seedbed Temperatures

Yellow willow seeds had their highest mean germination in the categories of seedbed temperatures of very cold, cold, and moderate (table 2). Germination was markedly reduced only at warm fluctuating and warm seedbed temperature categories. Note that the categories of seedbed
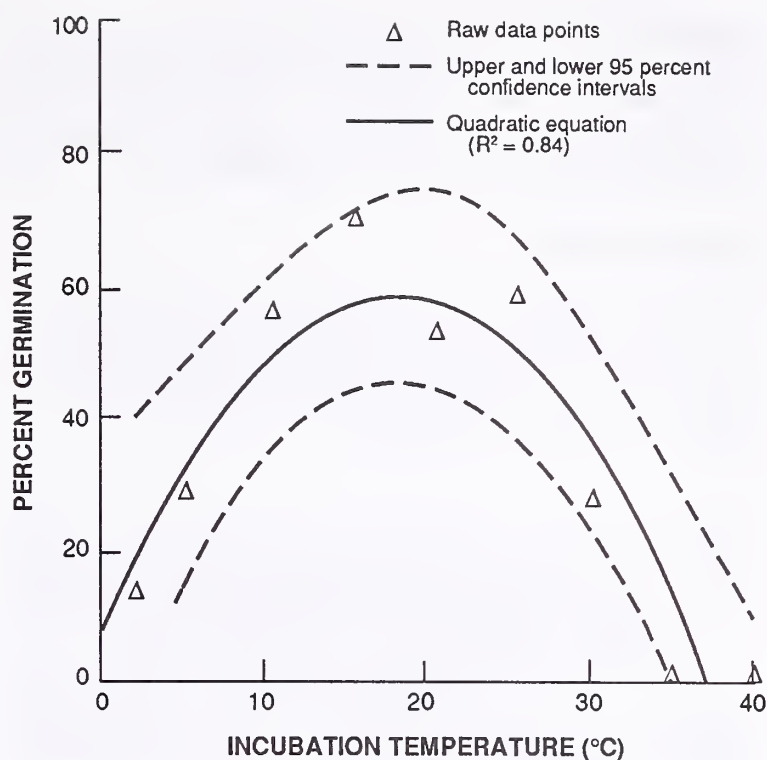

Figure 1—Germination of willow seeds as a function of incubation temperature.

Table 1—Germination profile with percentage germination for seeds[1] of yellow willow at 55 constant or alternating incubation temperatures

Cold period °C	Warm period (°C)									
	0	2	5	10	15	20	25	30	35	40
	------------------ Percent -----------------									
0	37	29	5	32	26	22	20	19	17	7
2		27	7	52	27	50	28	10	19	2
5			22	29	32	40	33	13	21	4
10				15	19	9	36	17	13	7
15					26	18	33	16	20	1
20						30	30	27	8	6
25							34	17	23	5
30								4	8	8
35									15	5
40										0

[1]These are actual germination figures, not means generated for quadratic response surface by regression equation as is the usual method of presenting germination profiles.

Table 2—Mean percentage germination of seeds of yellow willow at categories of seedbed temperatures

Seedbed temperature categories	Percentage germination
Very cold	25
Cold	28
Cold fluctuating	19
Warm fluctuating	10
Moderate	24
Warm	8

temperatures were based on test trial seedbeds in big sagebrush (*Artemisia tridentata* Nutt.) plant communities during the spring germination period. Microenvironmental monitoring data for temperature regimes in riparian habitats are not available to our knowledge.

Seed Storage

Seeds of yellow willow can be stored for at least 7 weeks and retain some viability. Storage in cold water indicates the seeds might be able to remain viable in riparian habitats for some time. Viability dropped rapidly when the seeds were desiccated (table 3).

Table 3—Percentage germination of seeds of yellow willow following storage in different environments from 0 through 7 weeks. Following storage, seeds were incubated at 20 °C

| Storage period | Storage environments[1] | | | |
	Laboratory paper bag	Frozen paper bag 0 °C	Water 2 °C	Desiccator over CaCl$_2$ 0 °C
Weeks	------------------ Percent ----------------			
0	25 bc	25 bc	25 bc	25 bc
2	(^{2})	48 ab	31 b	2 d
4	58 a	56 a	35 b	5 d
6	30 b	41 ab	28 b	0 d
7	5 cd	24 bc	40 ab	1 d

[1]Estimated germination percentages followed by the same letters are not significantly different based on overlap of the confidence intervals at the $\alpha = 0.05$ level.
[2]Data missing.

DISCUSSION

Seeds of yellow willow are initially quite viable as indicated by substantial germination over a wide range of temperatures. Apparently the seeds retain some viability over a period of several weeks if protected from desiccation. What is needed to interpret these results is microenvironmental monitoring of willow seedbeds in riparian environments and experimental data on natural and artificial seedling establishment in these seedbeds.

REFERENCES

Brinkman, K. A. 1974. *Salix* L. Willow. In: Seeds of woody plants in the United States. Agric. Handb. 450. Washington, DC: U.S. Department of Agriculture, Forest Service: 746-750.

Evans, R. A.; Holbo, H. R.; Eckert, R. E., Jr.; Young, J. A. 1970. Functional environment of downy brome communities in relation to weed control and revegetation. Weed Science. 18: 89-97.

Young, J. A.; Evans, R. A. 1982. Temperature profiles for germination of cool season grasses. Agric. Res. Results ARR-W-271 November. Oakland, CA: U.S. Department of Agriculture, Agricultural Research Service. 92.

DESIGN CRITERIA FOR REVEGETATION IN RIPARIAN ZONES OF THE INTERMOUNTAIN AREA

Jack R. Carlson
Gary L. Conaway
Jacy L. Gibbs
J. Chris Hoag

ABSTRACT

The design criteria for the Soil Conservation Service chan-nel vegetation practice for the Intermountain area consider watershed condition, geomorphology, stream types, commu-nity types, stream size, velocity, sinuosity, and bank slope, uniformity, and stratigraphy. Performance standards ad-dress benefits to soil stability, fish and wildlife habitat, water quality, and esthetic and recreational value. Speci-fications are developed for mass, pole, and stump or post plantings. Certain bioengineering practices also are appli-cable for riparian zones.

INTRODUCTION

The channel vegetation practice (Soil Conservation Ser-vice 1977) is a relatively recent addition to the Soil Conser-vation Service (SCS) National Handbook of Conservation Practices. Although SCS has been actively involved with vegetative treatment in riparian zones since the inception of the agency in the 1930's, it usually was accomplished as an auxiliary treatment within structurally oriented prac-tices, such as open channel, streambank protection, and stream channel stabilization. With increasing emphasis on multiple resource concerns, including fish and wildlife habitat, water quality, water conservation, and esthetics in addition to erosion control and water conveyance, SCS consolidated its riparian vegetative technology into the channel vegetation practice in 1977.

The practice standard definition for channel vegetation is the establishment and maintenance of vegetation on the banks of open channels, streams, and ditches. The practice imparts several conservation effects: bank stability, in-creased fish and wildlife habitat index values, filtered sur-face runoff from adjacent lands, improved watershed hydro-logic condition, and increased esthetic and recreational value. Most SCS State Offices have supplemented the na-tional standard with practice design criteria tailored to physiographic regions (examples include Carlson 1979; Soil

Conservation Service 1986). Although not excluding herba-ceous species, the practice focuses on the use of woody veg-etation to achieve the desired effects.

The channel vegetation practice primarily is used for treatment in riparian zones along streams. Streams in-clude those types classified by Rosgen (1985), or the river-ine wetland/deepwater systems described by Cowardin and others (1979). The revegetation technology of the practice also applies to transition (riparian) zones along reservoirs and lakes. In contrast, the SCS wetland restoration and development practice (Soil Conservation Service 1989) ad-dresses vegetative treatment within marine, estuarine, lacustrine, and palustrine wetland/deepwater systems.

SCS currently defines riparian zones as natural ecosys-tems occurring along watercourses or water bodies, occupy-ing the transitional area between terrestrial and aquatic ecosystems. It is evident in the literature that a widely accepted classification system for delineating riparian eco-systems in relation to aquatic and terrestrial ecosystems, and for classifying sites within riparian zones, has not been fully defined (see Brown and others 1979; Driscoll and oth-ers 1984; Kovalchik and Chitwood 1990; Minshall and others 1989; Swanson and others 1988). However, despite this, the concept of riparian zones is sufficiently clear to develop sound design criteria for revegetation.

The intent of this paper is to update the design criteria for the SCS channel vegetation practice for riparian zones in the Intermountain area, drawing on recent research findings, resource inventories, and technical reports.

INITIAL DESIGN CONSIDERATION: CONDITION OF THE WATERSHED

Riparian zones inherently are dynamic and very sensi-tive to changes in management that affect the hydrology of the watershed. Revegetation specialists must be familiar with the condition of upland vegetation and trends in com-position and use. If the hydrology of the watershed is af-fected by overgrazing, excessive logging, major construc-tion, or other activity, and this is visibly evident in the reaction of the stream within the riparian zone, a channel vegetation planting will have a greatly increased chance of failure.

Use historical information, aerial photos, condition of existing riparian zone vegetation, and other aids to assess whether the stream is in equilibrium with the management of the watershed. If not, upland management treatments

probably are necessary before it is safe to install the channel vegetation practice.

PRIMARY DESIGN CONSIDERATIONS: GEOMORPHIC VALLEY-FORM, STREAM TYPE, AND COMMUNITY TYPE

Riparian plantings often fail because they are subjected to hydraulic forces during high stream flow that exceed their capability to withstand, especially during the establishment period. Revegetation specialists should use geomorphic valley-forms described by Minshall and others (1989) for the Great Basin as an initial guide for determining the feasibility of installing the channel vegetation practice. The classes of geomorphic valley-forms are glacial headwaters, glacial valleys, erosional fluvial canyons, depositional fluvial canyons, alluvial valleys, and lacustrine basins. Valley-form classes also are similar to and not inconsistent with the riparian landforms described by Kovalchik and Chitwood (1990) for parts of eastern Oregon.

The six geomorphic valley-forms can be correlated to the stream types described by Rosgen (1985) and to vegetation community types described by Youngblood and others (1985), Padgett and others (1990), and inferred from Brunsfeld and Johnson (1985). In doing so, alluvial valleys are subdivided into a mid- and low-elevation phase, and braided stream channels are dealt with separately.

Glacial Headwaters and Valleys

These two geomorphic classes are combined and include palustrine wetlands in glacial basins high in organic matter, and broad U-shaped valleys containing rivulets and small streams.

Stream Characteristics—Small, low-order streams, probably Rosgen C-type; highly permeable substrate provides underground reservoir, which minimizes flooding during high precipitation and runoff; low velocity, often meandering.

Vegetation—Primarily wetland species (*Carex, Eleocharis, Juncus*), with levees and hummocks supporting low-growing willows *Salix planifolia, S. wolfii.*

Revegetation Potential—Stream should be allowed to move within confines of broad valley in most situations; revegetation should focus on restoration of unnaturally disturbed sites, using native willows on levees and hummocks.

Erosional Fluvial Canyons

Stream Characteristics—High-gradient, high-velocity, highly confined, down-cutting, low- to mid-order streams in V-shaped canyons; corresponds to Rosgen A stream types.

Vegetation—Narrow band of riparian vegetation along stream with primarily deep-rooted species; community types include dominants river alder (*Alnus incana*), water birch

(*Betula occidentalis*), and aspen (*Populus tremuloides*); associated species are native Booth and Geyer willows (*Salix boothii, S. geyeriana*), chokecherry (*Prunus virginiana*), serviceberry (*Amelanchier* spp.), dogwood (*Cornus* spp.), mockorange (*Philadelphus* spp.), and other forest shrub understory species.

Revegetation Potential—Relatively low due to high flow velocities; plantings usually will have little impact other than esthetic, unless most of the canyon vegetation, including riparian, has been destroyed; plantings must be made in protected areas behind boulders and along small backwaters; bioengineering techniques, such as wattling and fascines, may be employed to control canyon slope sloughing into stream.

Depositional Fluvial Canyons

Stream Characteristics—Moderate to high gradient and velocity, moderately to highly confined, low- to mid-order streams in V-shaped canyons, where deposition has occurred with the formation of a small flood plain; canyon walls confine stream, restricting meandering; corresponds to Rosgen B stream types; flow regimes are characterized by high disparity between maximum and minimum discharges, resulting in scoured floodplains or incised channels.

Vegetation—Stream terraces support relatively deep-rooted river alder, water birch, aspen, or cottonwood (*Populus trichocarpa, P. angustifolia, P. fremontii*); dogwood, serviceberry, and chokecherry are common shrub components; Geyer and Booth willow are the most common willows, but also prevalent are whiplash willow (*S. lasiandra* ssp. *caudata*), sandbar willow (*S. exigua* ssp. *melanopsis*), and Drummond willow (*S. drummondiana*).

Revegetation Potential—Relatively low due to high flow velocities and floodplain scouring; effects of revegetation are low unless the riparian zone and adjacent uplands have been drastically disturbed; plantings usually are limited to supplementing structures built on the floodplain, such as bridges; plantings must be made in protected areas; bioengineering techniques, such as live cribwalls, may be successful.

Braided Stream Channels

Stream Characteristics—Moderate gradient and velocity, unconfined braided channel form; often located where fluvial canyons empty into broad valleys and deposit coarse sediments; these zones are naturally highly erodible; corresponds to Rosgen D stream types.

Vegetation—Gravel bars and secondary channels may support cottonwood, sandbar willow, and other species that establish on freshly deposited sediment.

Revegetation Potential—Poor to fair; plantings are vulnerable to channel shifting; stream should be allowed to move as needed; consider establishing, protecting, and maintaining parent trees and shrubs as seed sources if large areas are denuded.

Mid-Elevation Confined Alluvial Valleys

Stream Characteristics—Low gradient and velocity; meandering pattern; small- to medium-sized, low- to mid-order streams, usually moderately confined; 5,000-7,000 feet elevation in north, higher moving south; corresponds to Rosgen C stream types.

Vegetation—Booth and Geyer willow dominate most communities on soils too waterlogged for deeper rooted alder, birch, and cottonwood; deeper rooted species may occur on small terraces where access to aerated water is available.

Revegetation Potential—High, using Booth and Geyer willow as primary species; river alder, water birch, and cottonwood may be planted where site conditions permit.

Low-Elevation Unconfined Alluvial Valleys

Stream Characteristics—Low gradient and velocity, highly sinuous, slight to no confinement; corresponds to Rosgen C stream types; sediments are much finer, but substantial water may percolate into the valley groundwater reservoir; evaporation also is significant in large, hot, arid Great Basin valleys; streamflow may be greatly reduced as it proceeds to lacustrine basins.

Vegetation—Black cottonwood (north and west), narrow-leaf cottonwood (east), and Fremont cottonwood (south) are very common depending on location within the Great Basin; usually associated with coyote willow (*Salix exigua* var. *exigua*) and yellow willow (*S. lutea*); for smaller streams, these two willows may be the dominant woody vegetation on soils too waterlogged for cottonwood.

Revegetation Potential—High, using native cottonwood or willow; a typical planting along medium to large streams includes willows established at the waterline and cottonwoods with understory shrubs on the upper bank and low terraces.

Lacustrine Basins

Stream Characteristics—Slow-moving, often ephemeral streamflow; often saline-alkaline soil conditions; may terminate into saline lake, dry lake bed, or playa.

Vegetation—May include cottonwood and willow if in a freshwater environment, or salt-tolerant species such as saltcedar (*Tamarix* spp.) or introduced Russian olive (*Elaeagnus angustifolia*); intermittent streams may support saltbushes (*Atriplex* spp.), greasewoods (*Sarcobatus* spp.), or rabbitbrushes (*Chrysothamnus* spp.).

Revegetation Potential—High, where not excessively saline-alkaline, using native species.

ADDITIONAL DESIGN CONSIDERATIONS

In general, low- to mid-order meandering streams are more suitable for revegetation than larger streams, which can be more likely to have catastrophic flooding events with localized highly erosive flow velocities. For small streams, the ratio of revegetation biomass to volume of flow is greater and more favorable for stability purposes. For large streams, the point of greatest erosive force often lies below the low waterline on the outside of meanders, making plantings vulnerable to undercutting unless the toe is stabilized structurally. Large streams also are more susceptible to ice flows, which can scour and denude a vegetated streambank. On the other hand, larger streams often are dammed for flood control and irrigation, which tends to reduce spring peak flows and produce long-duration moderate flows during the summer.

Streamflow Velocity

Where woody revegetation is subject to direct attack during high-water events, average stream velocity for mid-to-large streams should not exceed 5 feet per second for extended durations. A fully revegetated streambank can withstand flows up to 8 feet per second for relatively short duration. There is very little published information on the relationship of the stability of woody bank linings to flow velocity. Parsons (1963) evaluated streambank willow plantings in the Northeastern United States and equated a fully developed stand of densely stemmed purple-osier willow (*S. purpurea*) to a blanket of 6-inch angular riprap. Other than this useful information, the criteria given here are inferred primarily from field experience and from research on the hydraulic resistance of grassed waterways (Temple and others 1987).

Average stream velocity through the reach to be treated should be computed using data obtained from at least three representative cross-sections (usually above, below, and midpoint; or point bar, outside curve, next point bar on meandering streams). Stream gradients are below 1 percent, with greatest success when approaching and less than 0.1 percent.

Stream Sinuosity

Revegetation generally is feasible when the stream curve radius to stream width ratio exceeds 10 (Klingeman and Bradley 1976). Using Rosgen's classification scheme, sinuosity values of 2.4 and higher (stream length to valley length ratio) signify suitability of the riparian zone for revegetation.

Streambank Slope and Uniformity

Vegetative performance is affected by bank slope. For example, a 3:1 bank on a large stream will experience only moderate velocities, but a 1.5:1 bank (natural repose) will be subject to high velocities and significantly more erosion (Klingeman and Bradley 1976). Therefore, streambanks to be treated should be 3:1 or flatter, except for those between jetties, which may be 2:1 or flatter.

Bank irregularities cause local scour, which often leads to greater failure. Examples are uneven bank surfaces, abrupt changes in density and form of riparian vegetation, trapped debris, and changes in soil type. Each must be considered for its effect on the energy of the stream. Insofar as possible, a streambank on mid- to large-sized streams

subject to upper flow velocity limits should be made as uniform as possible before planting.

Streambank Stratigraphy

The stability of a streambank also depends on the layers of deposited material through which the stream has incised. Fine-textured bank soil may be quite resistant to stream tractive forces or seepage pressure, but erosion of an underlying gravel layer may cause undercutting and collapse of the entire bank. Vegetative treatment may need to be supplemented with structural measures for complex situations.

REVEGETATION PERFORMANCE CRITERIA

Conservation effects of the channel vegetation practice can be measured or estimated for the various resources it impacts.

Soil Stability

Vegetative bank protection is provided by: (1) aboveground stems diffuse erosive tractive force of water against the bank surface, and (2) the root mass, when exposed, provides an "armored" blanket resistant to erosion. No visible sign of bank erosion or bank sloughing should be evident. Stem densities are high enough to preclude passage by livestock, and with difficulty, by humans.

Wildlife Habitat

Riparian zones provide more diverse food, water, and cover for wildlife than most other ecosystems. Streambank plantings can maintain or reclaim habitat where competing land uses tend to reduce plant diversity and density along streams. Plantings should be as diverse in composition as the major components of the target plant community type.

Mudd (1975) found that optimum wildlife habitat value in eastern Washington along the Touchet River was realized when riparian zones were approximately 150 feet wide. This width is recommended for medium-to-large streams in the Intermountain area for plantings focused on wildlife habitat. Where possible, determine habitat suitability indices (U.S. Fish and Wildlife Service 1980) for target wildlife species to assess benefit of riparian plantings.

Fish Habitat

Analyze benefit to fish habitat by using comprehensive procedures recommended by Platts and others (1987) to evaluate shading and other fish habitat factors in the stream reach that has been revegetated. Use fish models to determine habitat suitability indices for target species.

It should be recognized that bank stability recommendations, which emphasize reduction of stream irregularities, may conflict with fish habitat recommendations, which encourage bank undercuts and diverse microenvironments within the stream. In general, a channel vegetation practice should not reduce habitat for target fish species, and with few exceptions, should increase its value.

Water Quality

Sediment is the most widespread and destructive water pollutant of fish habitat. Bank vegetation not only minimizes erosion but also intercepts sediment from adjoining lands. Riparian vegetation should be as wide as possible to adequately filter the sediment, with a recommended minimum width of 20 feet for this purpose, preferably wider. These buffer strips also should contain sufficient herbaceous understory plants and litter for adequate ground cover at the bank surface.

TYPES OF CHANNEL VEGETATION PLANTINGS

High-density mass plantings utilize hardwood cuttings or whips, bareroot seedlings or rooted cuttings, and container transplants planted 1 to 3 feet apart. This type of planting often is employed on bank slopes between jetties, slopes above riprap placed to the low-water mark, and on graded, set-back banks along low-velocity streams.

The intent is to maximize stem densities on the bank. As plant material usually is small, favorable planting conditions, including good moisture and slight to no weed competition, are required for success.

Pole Plantings

Dormant poles, ranging to 20 feet in length of easily rooting species, such as cottonwoods, are used in more difficult conditions. Poles are used to reach water tables to ensure rooting, provide enough aboveground height to escape shading by weeds and browsing by large animals, and to resist burial by bank sloughing. Pole plantings are less likely to wash out due to greater structural attributes.

Stump or Post Plantings

These are similar to pole plantings, except that larger diameter plant material is used, and lengths usually range from 6 to 10 feet. The best species are tree willows. Structural properties are emphasized, using "piling" or "breakwater" concepts. Larger stumps have thick bark, which resists wind, sun, and sand abrasion. Stumps also are planted into the water table to ensure rooting. On small streams, shrub willows may be used for smaller scale stump plantings, and are especially useful in incised channels where bank sloughing is prevalent.

Bioengineered Vegetative Structures

These may include willow wattles, fascines, and live cribwalls, among other techniques (Gray and Leiser 1982). Design criteria and specifications for these practices are under development as a supplement to the SCS Engineering Field Manual.

CHANNEL VEGETATION PRACTICE SPECIFICATIONS

Exposed streambanks to be planted must be shaped to recommended uniformity and slope, and the toe of the bank must be stable. If possible, the upper end of the planting should be within a stable reach of the stream. For mass plantings, remove existing weeds and as much of the weed seed source in the topsoil as possible by grading or tillage. Surface water from adjacent uplands must be diverted or conveyed through the planting area in a nonerosive manner.

Water must not be deflected against the bank during the establishment period, so instream debris management may be advisable.

Plant Material

Use species native to the indigenous community type. Commercially grown nursery stock is higher quality and results in higher establishment rates. Native stand sources may be decadent, with inadequate carbohydrate reserves for good survival, and not extensive enough for large projects.

Hardwood cuttings should be a minimum of 18 inches long and 0.5-inch bottom diameter; whips 3 to 6 feet long, and minimum 0.75-inch diameter; poles 8 to 20 feet long, and 1.5 to 5 inches in diameter; and stumps 4 to 10 feet long, and 2 to 8 inches in diameter. Butt ends of larger dormant stock should be cut at a 45-degree angle, and the growing end cut flat and treated with tree paint or other suitable sealant. Stump bark should be scored with a sharp object to encourage rooting.

Bareroot or container transplants should comply with common nursery quality standards.

Planting Configuration

Visualize the mature planting and whether it will deflect flows and provide other desired benefits. Plantings should provide a minimum-width bank lining of 20 feet. Mass and pole plantings should be a minimum of two parallel rows wide in staggered or diamond pattern, with no breaks or gaps in the planting. Stump plantings may be planted in a single, unbroken row at the base or below the toe of the bank.

Mass planting spacings range from 1.5 to 3 feet; pole and stump plantings 2 to 6 feet, depending on size of the plant material. Spacings may be somewhat wider on the upper bank.

Planting Methods

All dormant cuttings, whips, poles, or stumps must be planted to the summer water table depth, if necessary using augers to drill sufficiently deep holes to reach moisture. Bareroot or container plants may be planted at or just above the waterline, or on upper banks if weed competition is slight and moisture adequate. Comply with standard woody transplanting procedures (see Platts and others 1987).

Where bank sloughing is a potential problem, minimize burial by planting at an angle nearly perpendicular to the natural angle of repose.

Consider installing the practice in stages, particularly if both sides of the stream are being planted. Plant outside curves first, and plant remaining sites, if needed, after the initial plantings establish.

Planting Dates

In plant-hardiness zones 6 and below (average annual minimum temperature below 0 °F), install plantings in the early spring in March to mid-April; in zones 7 and above, from November to early March.

Weed Control

Expect many weeds the first year as riparian zones contribute a wide variety of wind- and waterborne seeds, mostly undesirable (often noxious) introduced weeds, to a newly planted bank. A typical erosion control seeding may provide severe competition to woody plantings and may encourage rodent populations, which may girdle woody plants. Consider mulching with gravel or bark around woody plantings in lieu of seeding groundcovers. Bank areas not planted to woody plants should be seeded to reduce safe sites for weed invasion.

Grazing or Browsing Management

Plantings require 3 years of unimpeded growth to fully establish. Provide protection from browsing by large animals as necessary.

Maintenance

Replant any failed portion of the practice during establishment and succeeding years. If stability is the primary objective, consider periodic pruning to maintain or increase stem densities. Riparian zones are dynamic, so expect changes in stream course, plant composition, and structure. Continuous monitoring is recommended.

TECHNOLOGY NEEDS

To strengthen the design criteria for the channel vegetation practice in the future, the following actions are recommended:

1. Develop a consensus among resource agencies and groups on a hierarchical riparian site classification, which will enable individual riparian sites to be rated for suitability for revegetation.
2. Conduct further research into the relationship between performance of bank vegetation and the hydraulic properties of the stream.
3. Conduct research on the compatibility of herbaceous groundcovers with woody plants in riparian plantings.
4. Develop monitoring procedures and a data/knowledge base that capture the long-term performance of channel vegetation plantings made throughout the Intermountain area.

REFERENCES

Brunsfeld, S. J.; Johnson, F. D. 1985. Field guide to the willows of east-central Idaho. Bull. 39. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station. 95 p.

Carlson, J. R. 1979. Streamside revegetation. SCS Plant Materials Tech. Note 55. Portland, OR: U.S. Department of Agriculture, Soil Conservation Service. 9 p.

Gray, D. H.; Leiser, A. T. 1983. Biotechnical slope protection and erosion control. New York: Van Nostrand Reinhold. 271 p.

Jensen, S. E.; Platts, W. S. 1989. Restoration of degraded riverine/riparian habitat in the Great Basin and Snake River regions. In: Kusler, J. A.; Kentula, M. E., eds. Wetland creation and restoration: the status of the science. EPA/600/3-89/038A. Corvallis, OR: U.S. Environmental Protection Agency, Environmental Research Laboratory: I: 377-408.

Klingeman, P. C.; Bradley, J. B. 1976. Willamette River basin streambank stabilization by natural means. Portland, OR: U.S. Army Corps of Engineers. 238 p.

Kovalchik, B. L.; Chitwood, L. A. 1990. Use of geomorphology in the classification of riparian plant associations in mountainous landscapes of central Oregon, U.S.A. Forest Ecology and Management. 33/34: 405-418.

Minshall, G. W.; Jensen, S. E.; Platts, W. S. 1989. The ecology of stream and riparian habitats of the Great Basin region: a community profile. Biol. Rep. 85(7.24). Slidell, LA: U.S. Department of the Interior, Fish and Wildlife Service, National Wetlands Research Center. 142 p.

Mudd, D. R. 1975. Touchet River study, part 1, wildlife. Appl. Res. Bull. 4. Olympia, WA: Washington State Game Department. 43 p.

Padgett, W. G.; Youngblood, A. P.; Winward, A. H. 1989. Riparian community type classification of Utah and southeastern Idaho. R4-Ecol-89-01. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 191 p.

Parsons, P. A. 1963. Vegetative control of streambank erosion. In: Federal interagency sedimentation conference: proceedings. Misc. Publ. 970. Washington, DC: U.S. Department of Agriculture, Agricultural Research Service: 130-136.

Platts, W. S.; Armour, C.; Booth, G. D.; [and others]. 1987. Methods for evaluating riparian habitats with applications to management. Gen. Tech. Rep. INT-221. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 177 p.

Rosgen, D. L. 1985. A stream classification system. In: First North American riparian conference: proceedings; 1985 April 16-18; Tucson, AZ. Gen. Tech. Rep. RM-120. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 91-95.

Soil Conservation Service. 1977. Channel vegetation, national practice standard. National List of Conservation Practices. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service: 322: 1-2.

Soil Conservation Service. 1986. Dormant stock planting for channel stabilization. SCS Biol. Tech. Note 22. Phoenix, AZ: U.S. Department of Agriculture, Soil Conservation Service. 19 p.

Soil Conservation Service. 1989. Wetland development or restoration, national practice standard. National List of Conservation Practices. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service: 690: 1.

Swanson, S.; Miles, R.; Leonard, S.; Genz, K. 1988. Classifying rangeland riparian areas: the Nevada Task Force approach. Journal of Soil and Water Conservation. 43(3): 259-263.

Temple, D. M.; Robinson, K. M.; Ahring, R. M.; Davis, A. G. 1987. Stability design of grass-lined open channels. Agric. Handb. 667. Washington, DC: U.S. Department of Agriculture, Agricultural Research Service. 175 p.

U.S. Fish and Wildlife Service. 1980. Habitat evaluation procedures (HEP). Ecological Services Manual ESM 102. Washington, DC: U.S. Fish and Wildlife Service, Division of Ecological Sciences. 128 p.

ESTABLISHMENT AND GROWTH POTENTIAL OF RIPARIAN SHRUBS IN THE NORTHERN SIERRA NEVADA

Tony J. Svejcar
Gregg M. Riegel
Scott D. Conroy
James D. Trent

ABSTRACT

Over the past several years, a number of studies involving willows and riparian systems have been conducted in the Lake Davis area in the northern Sierra Nevada. Results from a planting study suggest that successful establishment of Geyer's willow (Salix geyeriana) cuttings can be achieved if the base of the cutting is within 30 cm of the midsummer water table depth. Physiological studies of Lemmon's willow (S. lemmonii) indicate there was a shorter period of active photosynthesis and lower maximum rates during the drought year of 1988 compared to 1989 when precipitation was near average. Another finding was that willow leaves had very low photosynthetic rates during the first 4 to 6 weeks of growth. Soil oxidation-reduction potential and water table depth were measured from the streambank to meadow/forest boundary during 1990. Results indicate that both redox potential and water table depth can change very quickly, even in the streambank. Thus, willows can be established successfully, but the delay in active photosynthesis of willow leaves and rapidly changing soil conditions during midsummer may place constraints on willow planting success.

INTRODUCTION

The emphasis on management of riparian vegetation has changed dramatically during the past 30 years. Early research demonstrated that clearing woody riparian vegetation could result in increased streamflows during the summer (Rowe 1963). There were cost-share arrangements between landowners and government agencies to improve water yield by removing woody vegetation during the 1940's and 1950's. Campbell (1970) suggested that selective removal of woody species rather than complete removal of riparian species might help increase water yields while maintaining a biological balance in the riparian zone. More recently we have come full circle and are now trying to establish woody vegetation in stream systems as a means of stabilizing streambanks and restoring hydrologic processes in the appropriate stream ecosystems.

In spite of the interest in establishment of woody riparian vegetation in the Western United States, there is relatively little quantitative information on establishment success. Even less information is available concerning physiological and environmental factors influencing establishment. The studies presented in this paper are an attempt to gain information on these topics.

MATERIALS AND METHODS

The study sites were located about 10 km north of Portola in Plumas County, CA (fig. 1). Elevations ranged from 1,700 to 1,800 m and mean annual precipitation is 96 cm, 85 percent of which comes between October and
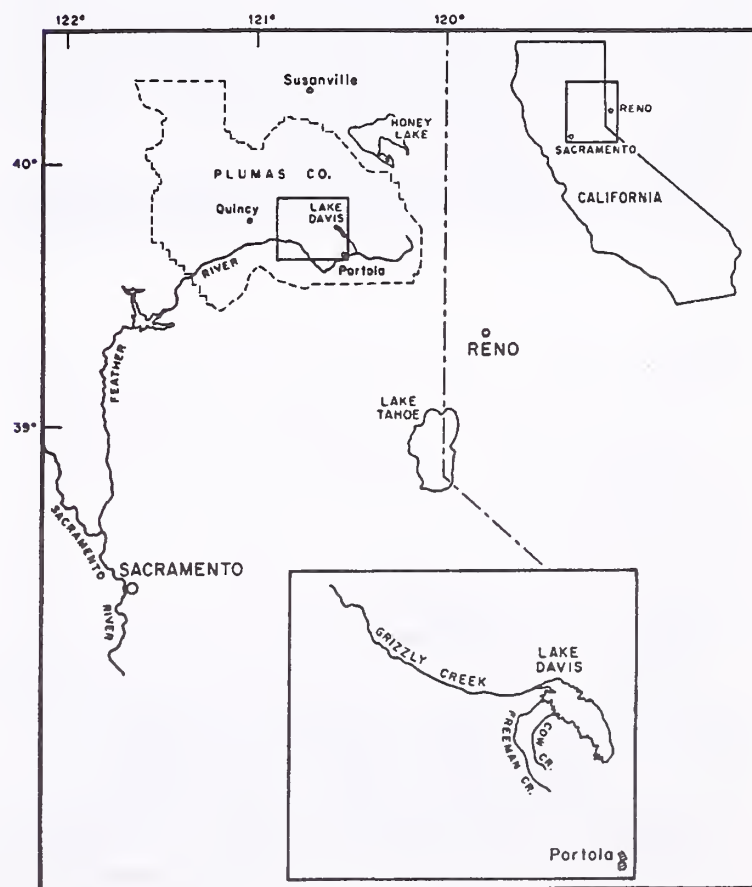
Figure 1—Location of study sites.

April, primarily as snow. Willows were planted along Cow, Freeman, and Big Grizzly Creeks in early May of 1987. A more detailed description of the study sites and procedures used in the willow planting experiment appears in Conroy and Svejcar (1991). The data presented here include survival of Geyer willow (*Salix geyeriana* Anderss.) cuttings planted in several community types and locations relative to the streams. Percent survival was determined in September 1987 and September 1988; we chose to present second-year survival (September 1988). Water table depths and soil moisture at each willow planting site were measured using observation wells and a neutron probe (Campbell Pacific Nuclear Model 503), respectively.

Seasonal trends in soil oxidation-reduction potential (redox) were measured during 1990 at a site on upper Grizzly Creek. Redox probes consisted of a 1.5-cm length of platinum wire, which was soldered into a steel welding rod. Heat-shrink tubing was used to encase the welding rod and Aquaseal® formed the waterproof union between the wire and encased rod. Pairs of redox probes were placed at 20- and 40-cm soil depths at sampling points located 2.5, 10, 20, and 50 m from the stream edge (fig. 2). The transect represented a gradient from stream edge to the meadow-forest boundary. There were 11 replicate transects located in five fenced exclosures and six grazed pastures. Means from controls and grazed pastures were combined as they were not significantly different ($p < 0.05$). A PVC salt bridge, which facilitates measurements under dry conditions, was located between the two redox probes at each sampling point. The salt bridge and AgCl reference electrode were necessary to complete the electrical circuit. A portable Ph/millivolt meter was used to measure redox potential. Water table depth was measured at 2.5, 5, 10, 20, 30, 40, and 50 m from stream edge along the sampling transects (fig. 2). At each sampling point, perforated 5-cm PVC observation wells were augered to a depth of 1.5 m. Measurements of water table depth were taken on May 4, June 4, and July 5, 1990.

A portable photosynthesis system (LI-6200, LiCor, Inc., Lincoln, NE) was used to measure photosynthetic rates of

Lemmon's willow (*Salix lemmonii* Bebb) at Freeman Creek during 1988 and 1989. Six replicate willow plants were measured during midafternoon throughout the growing season. Mature plants growing within 2 m of the stream were used.

RESULTS AND DISCUSSION

Willow cuttings could be planted in the streambottom or streambank with relative success, but survival was minimal in the stream terrace (table 1). The sites with observation wells and access tubes had somewhat lower willow survival than the averages for the entire 2,700 willow plants (Conroy and Svejcar 1991). However, the trends and relative comparisons are similar. We suspect that competition interacts with the abiotic environment to influence the success of willow establishment. The bareground sites had slightly lower water table depth and soil moisture than Dece/Cane sites, yet both survival and leader lengths were greater (table 1). Leader length was greater on the bareground sites than either of the other wet-site communities. The variability in leader length did not allow statistical separation of the means when only the subset of 90 sites was analyzed; however, the bareground sites were significantly higher in leader growth when the analysis included all willow cuttings (table 3, Conroy and Svejcar 1991). In Alaska, Densmore and others (1987) found that dense grass reduced willow growth or killed willows directly from shading or indirectly by stimulating vole browsing.

Competition may be a critical factor on some sites, but the high percent survival in the Cane/June community type (which had the highest water table level) suggests that the abiotic environment is probably the overriding factor. The speed with which abiotic conditions can change is indicated by the redox potential and water table depth (figs. 3 and 4). Redox potential is a quantitative measure of electron availability in chemical and biological systems, and can provide a relative measure of the availability of certain nutrients in saturated soils (Green and
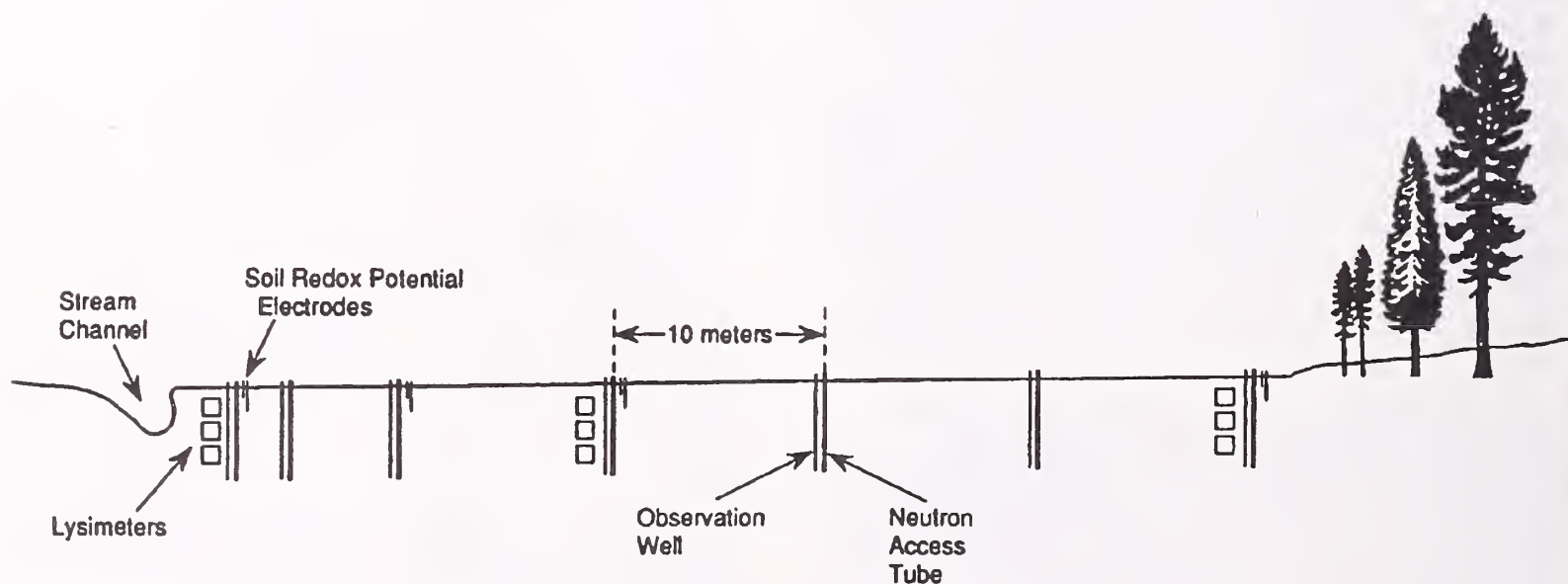

Figure 2—Schematic of sampling transect for soil oxidation-reduction potential and water table depth.

Table 1—Water table depth (cm) and soil moisture (percent volume at 30-cm depth) means and standard errors (in parentheses) on July 17, 1987. A total of 90 sites were included and survival is after two growing seasons

	Community type				
	Cane/June[1]	Bareground	Dece/Cane	Arca/Posa	Artr/Posa
Water table depth (cm)	41(13) a[2]	73(12) b	64(6) ab	121(2) c	122(9) c
Soil moisture (percent v)	51(6) a	43(8) ab	54(10) a	36(4) bc	30(1) c
Survival (percent)	64(12) a	52(2) a	22(12) b	6(6) b	8(8) b
Leader length (cm)	90(17)	170(50)	61(33)	—	—

	Location		
	Streambottom	Streambank	Stream terrace
Water table depth (cm)	27(6)	73(6) b	126(7) c
Soil moisture (percent v)	53(3) a	44(4) b	36(2) c
Survival (percent)	73(7) a	45(6) b	7(4) c
Leader length (cm)	171(69)	69(20)	59(9)

[1]Cane = *Carex nebrascensis*; June = *Juncus nevadensis*; Dece = *Deschampsia cespitosa*; Posa = *Poa sandbergii*; Arca = *Artemisia cana*; Artr = *A. tridentata* var. *vaseyana*.
[2]Different letters indicate treatment separation ($p \leq 0.05$) within rows.

Redox Potential – 20 cm Depth
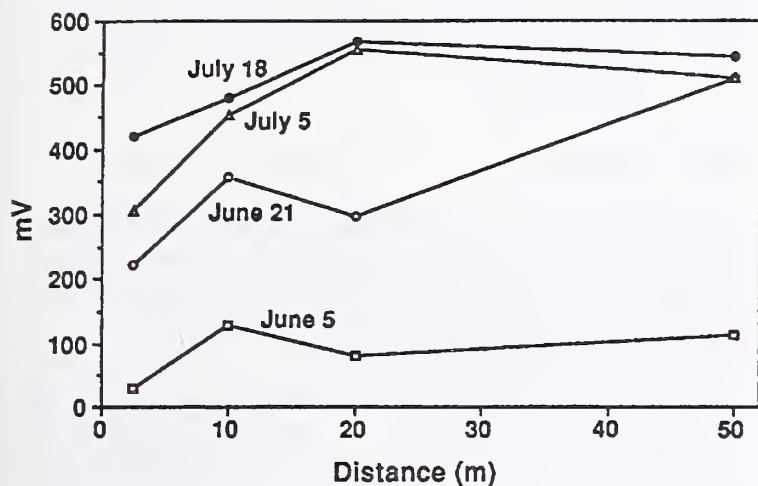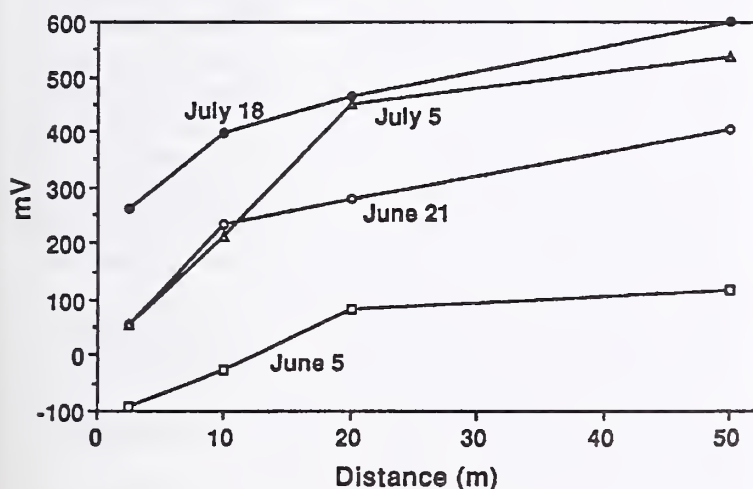

Redox Potential – 40 cm Depth

Figure 3—Seasonal trend in soil oxidation-reduction potential measured at 20- and 40-cm depths.
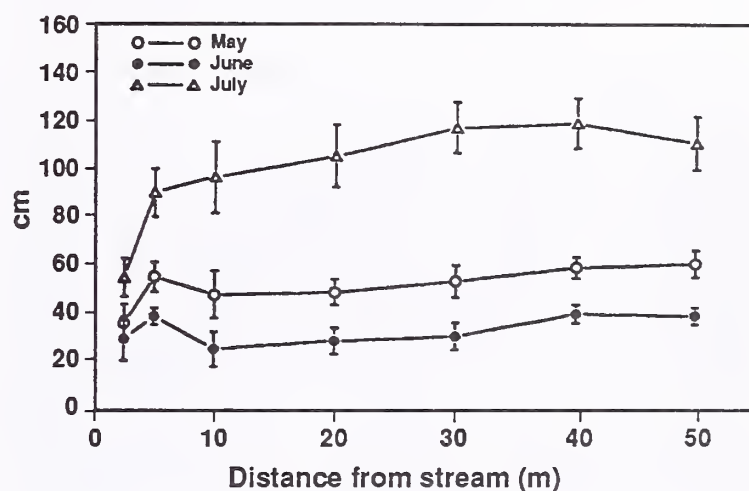

Figure 4—Seasonal trend in water table depth from streambank to meadow-forest edge. Measurements were taken on May 4, June 4, and July 5, 1990.

Kauffman 1989). Low redox potentials (–400 to 200 mV) are associated with reduced or submerged soils; well-oxidized soils have redox potentials of 300 to 800 mV (Green and Kauffman 1989; Ponnamperuma 1972). The reduced forms of Fe, Mn, and SO_3 can be toxic to plants, and occur under conditions of low redox potential. Under saturated conditions anaerobic bacterial populations increase, accounting for the majority of the decline in redox potential as they use compounds such as nitrate-nitrogen as terminal electrons acceptors (denitrification) (Brock and others 1984). Some species and communities are limited to soils with specific ranges and durations of redox potential (Green and Kauffman 1989). However, we are not aware of information on the adaptations of riparian species (including willows) to rapid changes in redox potentials. As expected, trends for water table depth (fig. 4) were similar to those for redox potential. The water table raised between early May and early June as a result of

late-spring rains. But the decline in depth during the month of June was rather dramatic.

A willow planting will have to break dormancy and initiate root growth rapidly during the late spring-early summer period. The year during which the soil redox and water table measurements were taken was below normal for snowpack (about 50 percent of average), so soil moisture depletion may have occurred more rapidly than in an "average" year. However, there may be many years when midsummer represents a period of rapid change in the riparian zone.

Willows exhibit rather unique photosynthetic characteristics that may have an effect on establishment pattern. Willows initiated leaf growth during early to mid-April of both years, yet photosynthetic rates remained low until early June of both years (fig. 5). Thus, there is a 4- to 6-week period where leaves are present, but carbon uptake is minimal. Measurements taken in early May of 1988 were discarded as a result of presumed equipment malfunction when none of the measurements yielded positive photosynthetic rates. However, subsequent measurements indicated the problem was with the willows, not

the photosynthesis meter. Presumably, the willows were using stored carbon during the early phase of growth. Maximum photosynthetic rates occurred in either July or August when air temperatures increased. During the drier of the 2 years (1988), photosynthetic rates were on the decline after early July, and maximum rates were lower than in 1989. The maximum photosynthetic rates measured in this study are comparable to those measured by Patton and Jones (1989).

If willow cuttings also exhibit a delay in achieving maximum photosynthetic rates, then the cuttings may be dependent on stored carbon for a longer period than previously assumed. Limitations to root growth before the midsummer decline in soil moisture may influence willow cutting establishment. Such a limitation might help explain why establishment of willows is difficult in areas where the water table drops much below the cutting placement depth during the midsummer period. Research into shoot and root growth of willow cuttings would provide additional insights on willow planting recommendations.

ACKNOWLEDGMENTS

REFERENCES

Brock, T. D.; Smith, D. W.; Madigan, M. T. 1984. Biology of microorganisms. Edgewood Cliffs, NJ: Prentice-Hall.

Campbell, C. J. 1970. Ecological implications of riparian vegetation management. Journal of Soil and Water Conservation. 25: 49-52.

Conroy, S. D.; Svejcar, T. J. 1991. Willow planting success as influenced by site factors and cattle grazing in northeastern California. Journal of Range Management. 44: 59-63.

Densmore, R. W.; Neiland, B. J.; Zasada, J. C.; Masters, M. A. 1987. Planting willow for moose habitat restoration on the north slope of Alaska, U.S.A. Arctic and Alpine Research. 19: 537-543.

Green, D. M.; Kauffman, J. B. 1989. Nutrient cycling at the land-water interface: the importance of the riparian zone. In: Gresswell, R. E.; Barton, B. A.; Kershner, J. L., eds. Practical approaches to riparian resource management: an educational workshop; 1989 May 8-11; Billings, MT. Billings, MT: U.S. Department of the Interior, Bureau of Land Management: 61-68.

Patton, L.; Jones, M. B. 1989. Some relationships between leaf anatomy and photosynthetic characteristics of willows. New Phytologist. 111: 657-661.

Ponnamperuma, F. N. 1972. The chemistry of submerged soils. Advances in Agronomy. 24: 29-96.

Rowe, P. B. 1963. Streamflow increases after removing woodland-riparian vegetation from a southern California watershed. Journal of Forestry. 61: 365-370.
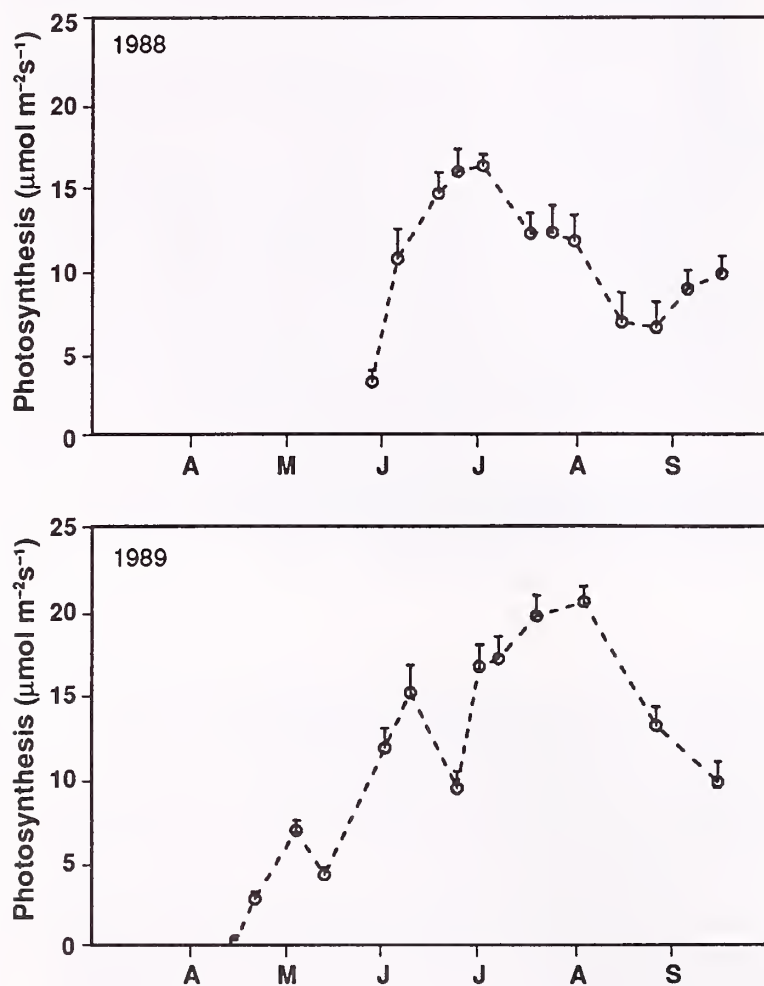
Figure 5—Seasonal trend in photosynthesis of Lemmon's willow during 1988 and 1989. Precipitation for 1988 and 1989 was 46 and 110 percent of average, respectively.

245

SEED SOURCE EVALUATION OF FOUR NATIVE RIPARIAN SHRUBS FOR STREAMBANK REHABILITATION IN THE PACIFIC NORTHWEST

T. R. Flessner
D. C. Darris
S. M. Lambert

ABSTRACT

To enhance vegetative restoration efforts, four native deciduous shrubs, Sitka alder (Alnus sinuata [Regel] Rydb.), Pacific serviceberry (Amelanchier alnifolia var. semiintegrifolia [Hook.] Hitchc.), oceanspray (Holodiscus discolor [Pursh] Maxim.), and vine maple (Acer circinatum Pursh), are currently being evaluated and selected for use in riparian areas. One seed source of Sitka alder and three of Pacific serviceberry have been selected for further testing. Evaluations for oceanspray and vine maple will continue into the late 1990's.

INTRODUCTION

Streambank erosion contributes up to 10 million cubic yards of sediment each year in the Pacific Northwest (Carlson 1979). Logging, grazing, mining, road building, and recreational use have contributed to the loss of 80 percent of woody riparian vegetation along stream corridors (Sherman 1989). These degraded streamside ecosystems often become dominated by weedy (introduced) grass species that hinder rehabilitation efforts. Development of improved varieties of native riparian shrubs will benefit restoration and stabilization essential for these areas. Sitka alder (*Alnus sinuata* [Regel] Rydb.), Pacific serviceberry (*Amelanchier alnifolia* var. *semiintegrifolia* [Hook.] Hitchc.), oceanspray (*Holodiscus discolor* [Pursh] Maxim.), and vine maple (*Acer circinatum* Pursh) are currently being propagated and evaluated for vigor, growth rate, stem and foliage density, form, fruit or seed production, disease symptoms or insect signs, and phenological development at the U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS) Plant Materials Center (PMC) at Corvallis, OR. Improved cultivars of these species also have potential for windbreaks, screens, naturalized plantings, wildlife habitat improvement, and other reclamation purposes.

Common garden seed-source studies or provenance tests were established for Sitka alder and Pacific serviceberry in

1983, and evaluations will be conducted through the early 1990's. A randomized, replicated planting of oceanspray populations was established in 1989, and a similar investigation of vine maple populations will be installed in 1992. Evaluations for these two species will be conducted through the late 1990's. Species descriptions, methods, and interim results of studies are discussed here.

SITKA ALDER

Sitka alder occurs from northern California to southern Alaska, east to northern Idaho and Montana, from sea level to 1,200 m (USDA Forest Service 1974, 1988). It often forms dense thickets in moist areas, particularly along streams and lakes. Sitka alder is an open, rounded shrub, usually 1.2-1.8 m tall, with smooth, gray bark, slender branches, and ovate, doubly serrate leaves. Male and female catkins mature in spring with the leaves, and small, conelike fruits and winged nutlets ripen in late fall or early winter (L. H. Bailey Hortorium 1976). Sitka alder is wind-pollinated.

Adaptive characteristics of Sitka alder include rapid initial growth rate and the ability to grow at a wide range of elevations on infertile soils. As a nitrogen-fixing, pioneer species, Sitka alder is often one of the first shrub species to appear following fire, landslides, clearcutting, and other natural or artificial disturbances (Binkley 1982; Bollen and others 1969; Cwynar 1987; Vann and others 1988). Acetylene reduction assays have yielded a nitrogen fixation estimate of 35 kg N/ha/yr (Binkley 1982).

Sitka alder is browsed by deer, elk, and moose, and its seeds are eaten by several species of small birds (L. H. Bailey Hortorium 1976; USDA Forest Service 1988). This species is susceptible to several fungal pathogens, including those that cause leaf spots, powdery mildew, canker, and heart rot (USDA Forest Service 1971). It is also host to a number of insects, including borers, scale, and black vine root weevil (*Otiorhynchus sulcatus*). The most severe losses observed have been due to weevils.

Sitka alder spreads naturally by rhizomes and seed (USDA Forest Service 1988). In practice, it may be successfully propagated via fresh seed, cold-moist stratification of dried seed, and tissue culture (Tremblay and Lalonde 1984; USDA Forest Service 1974). The use of softwood and hardwood cuttings has been less successful (Dirr 1983). Although grafting of other alder species is common, whip grafting of selected dormant stock of Sitka alder (9040484) was not successful. Sitka alder forms symbiotic associations

with nitrogen-fixing bacteria (*Frankia* spp.) and certain ec-tomycorrhizae. Inoculation of containerized seedlings or clones with these symbionts at planting or shortly thereaf-ter must be considered in conjunction with the fertilization regime (Molina 1981). Generally, alders prefer mineral soils, regular water supply, and full sunlight (Hibbs 1986).

Resource managers in the Pacific Northwest are increas-ingly using hardwoods not only to improve riparian areas, but also to increase site productivity, control certain root diseases, and enhance wildlife habitat (Miner 1990). For example, Sitka alder's low height, early slowdown in growth rate, and nitrogen-fixing capability make it desirable in rotations and mixtures with Douglas-fir (*Pseudotsuga men-ziesii*) (Binkley and others 1984; Harrington and Deal 1982; Heilman 1983). Any seed source selection should include an evaluation of nitrogen fixation rates.

Methods

Assembly of Sitka alder was initiated in 1982 and com-pleted in 1983. A total of 72 populations (accessions) were sampled by SCS personnel in western Washington, west-ern Oregon, and northern California, primarily within the Cascade Mountain Range (fig. 1). Collections originated from elevations between 15 and 1,798 m within a precipi-tation zone of 2,000-2,500 mm.

Seed was planted directly into 164-mL^3 containers in February-March 1983 in a greenhouse. Stock was grown under sprinkler irrigation and fertilized during the summer months. In October, seedlings of 64 accessions were hand-planted into chemically killed sod of hard fescue (*Festuca ovina* var. *duriuscula*), at the Corvallis PMC. Six accessions of red alder (*Alnus rubra*) were included for comparison. The planting site is a moderately well drained Woodburn silt loam soil and receives an average annual precipitation of 1,050 mm. The USDA Plant Hardiness Zone is 8b, and the frost-free growing season averages 210 days. Elevation is 69 m and slopes are 0-1 percent.

The study consists of single-row, nonreplicated plots; each plot contains six plants. Spacing between rows and plants is 3.7 m and 1.8 m, respectively. Chemical and mechanical means were used as needed for weed control between and within rows. No supplemental irrigation or fertilization was applied. Performance data, including survival, height, canopy width, vigor, stem density, cone production, foliage appearance, and average bud break and leaf drop dates were recorded annually, from 1984 to 1990. Vigor, stem density, cone production, and foliage appearance were vi-sually rated on a scale from 1 to 9, with 1 being excellent, and 9 poor.

Results

Accession 9040484 has been identified as the top per-former of 64 seed sources. Selection criteria included vigor, height, canopy width, first-year and following-years growth rates and lateral spread, stem density, cone production, fo-liage appearance, and average dates of bud break and leaf drop. Accession 9040484, originating in Skamania County, WA, was the only ecotype that placed in the top 10 percent in 10 of 12 criteria (table 1). Accessions 9037160, 9037130, 9037115, 9037136, and 9014018 placed in the top 10 per-cent in at least three of 12 criteria (table 1). Substantial
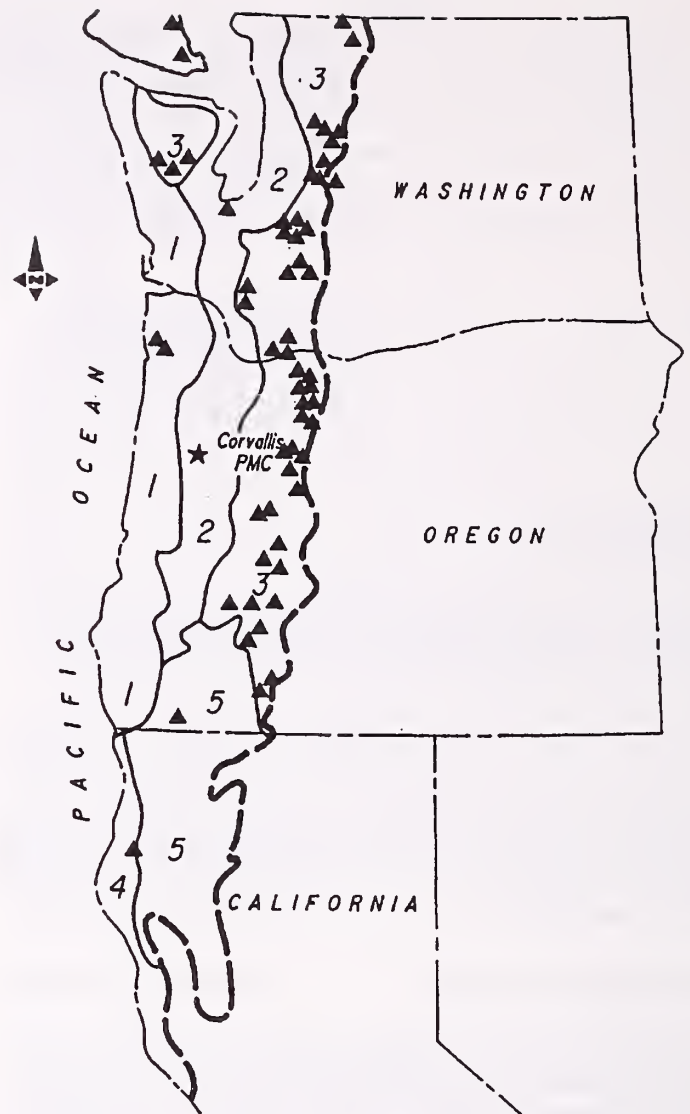
Figure 1—Collection sites for Sitka alder (*Alnus sinuata*). Note: Six accessions not shown. Numbers indicate USDA SCS Major Land Resource Areas.

genotypic variability in height, canopy width, growth rates, foliage appearance, and phenology was exhibited between accessions, but less so within accessions (table 1).

PACIFIC SERVICEBERRY

Pacific serviceberry occurs west of the Cascade and Sierra Nevada Mountain ranges, from British Columbia south to central California (USDA Forest Service 1974). It may be found in open woods, along canyons, or on hill-sides, from near sea level to subalpine altitudes (Anonymous 1976b). Pacific serviceberry is a thicket-forming shrub or small tree 3-12 m tall with smooth, brown bark, slender branches, and oblong leaves sharply and coarsely toothed along the upper margin. Clusters of perfect white flowers appear in spring, and dark purple to black berrylike pomes are produced in mid- or late summer (Elias 1980). This species may be self or cross-pollinated via insects (Olson 1984).

Pacific serviceberry is an excellent candidate for stream-bank restoration, as it tolerates many soil types and suck-ers profusely (Dirr 1983; L. H. Bailey Hortorium 1976). It

Table 1—Comparative survival, vigor, and growth characteristics of selected accessions of Sitka alder, evaluated at Corvallis PMC (data collected in 1990, unless otherwise noted).[1] Definitions of table headings are: ACC. # = accession number; SURV = mean percent survival; HT = mean height, in centimeters; GR = first-year (1983-1984) mean growth rate, in centimeters; GRO = mean growth rate, in centimeters, following the first year; CW = mean canopy width, in centimeters; LS = first-year (1983-1984) mean lateral spread, in centimeters; LSO = mean lateral spread, in centimeters, following the first year; V = mean vigor; SD = mean stem density; BY = mean first bloom year; FP = mean fruit production; BDBK = mean date of bud break (1984-1990); LFDP = mean date of leaf drop (1984-1990); FA = mean foliage appearance, based on relative occurrence of insect and disease signs or symptoms (1984-1990). Data represent means of plots

ACC. #	SURV	HT	GR	GRO	CW	LS	LSO	V	SD	BY	FP	BDBK	LFDP	FA
9040484	83	271	211	46	259	224	19	1	4	86	3	3/31	12/28	2
9037160	100	235	167	51	250	215	29	2	5	86	3	4/19	12/03	2
9037130	100	247	200	31	244	221	15	2	5	87	5	4/19	11/20	2
9037115	100	247	193	37	247	221	19	2	5	87	3	4/26	11/20	3
9037136	100	262	216	30	223	193	22	3	5	86	2	4/19	11/20	4
9014018	83	220	148	58	216	185	26	3	4	86	3	4/19	11/20	4
Grand mean	94	218	169	33	203	177	18	4	5	—	4	—	—	4
Range	50	140	93	3	131	101	4	6	6	86	7	4/09	10/23	8
	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	100	412	359	62	293	272	41	1	3	88	2	5/05	12/28	2

[1]Ratings: 1 = best; 9 = worst.

has also been found to increase in frequency following fire, although canopy cover decreased (Anderson and Bailey 1980). Pacific serviceberry is browsed by deer, moose, and other mammals; its fruit are relished by several species of song and game birds (Elias 1980; Marks and Marks 1988).

This species is susceptible to several pathogens, including those that cause rust, witches broom, fire blight, powdery mildew, leaf blights or spots, fruit rot, canker, root rot, and wound rot. It is also host to several insects, including leaf miners, borers, mites, sawflies, scale, and apple curculio (*Tachypterrellus quadrigibbus*) (Anonymous 1976b; Dirr 1983; USDA Forest Service 1971). Of these pests, rust, fire blight, and leaf blights cause the greatest losses; the apple curculio greatly reduces fruit yields (Steeves and others 1979; USDA Forest Service 1971).

Pacific serviceberry reproduces naturally by stolons and seed (L. H. Bailey Hortorium 1976). In nursery practice, cultivars may be propagated successfully by cold-moist stratification of dried seed, division, layering, grafting or budding, and tissue culture (Anonymous 1976b; Dirr 1983; Dirr and Heuser 1987; Nelson and Bishop 1980; USDA Forest Service 1974). Softwood cuttings taken from etiolated, field-grown, rejuvenated stock plants were rooted successfully (95 percent) under intermittent mist without hormonal treatment (Nelson 1987). Generally, the use of cuttings has not been successful (Bishop and Nelson 1980; Dirr 1983). Seed dormancy may be further reduced by selecting medium-weight seeds prior to cold-moist stratification (Weber and others 1982). Pacific serviceberry prefers moist, well-drained acid soil and full sun or partial shade (Dirr 1983). This species may be used effectively in naturalized plantings and as hedges or screens in urban areas, as well as for erosion control and improved wildlife habitat in riparian areas. Several cultivars of *Amelanchier alnifolia* are available for ornamental plantings and commercial fruit production in North America.

Methods

Assembly of Pacific serviceberry was initiated in 1981 and completed in 1982. A total of 77 populations were sampled by SCS personnel in western Washington, western Oregon, and northern California (fig. 2). Seven additional seed sources were also obtained; three of these were introduced from foreign countries, and four came from Colorado. The cultivar 'Smoky,' from Canada, was included as the standard for comparison. Collections originated from elevations between 30 and 1,219 m within a precipitation zone of 625-2,500 mm.

Freshly harvested seed was stratified in flats of moist sand at 4 °C for 125-174 days. Stratified seed was soaked in tap water and subsequently planted into 164-mL^3 containers in February 1983 in a greenhouse. Stock was grown under sprinkler irrigation and fertilized during the summer months. ('Smoky' did not survive and was thereafter excluded from the study.) In November, seedlings of 72 accessions were hand-planted into a clean bed, at the Corvallis PMC Berry Creek unit. The planting is on a well-drained Jory silty clay loam and a well-drained Willakenzie silty clay loam soil. The site receives an average annual precipitation of 1,200 mm. Elevation is 91 m, and slopes are 3-7 percent. A cover crop of hard fescue was established between rows for erosion and weed control.

The study consists of single-row, nonreplicated plots; each plot contains six plants. Spacing between rows and plants is 3.7 m and 1.8 m, respectively. Chemical and mechanical means were used as needed for weed control between and within rows. No supplemental irrigation or fertilization was applied. Performance data, including survival, height, canopy width, vigor, stem density, fruit production, foliage appearance, basal width (suckering), and average bud break and leaf drop dates were recorded annually, from 1984 to 1990. Vigor, stem density, fruit production, and foliage
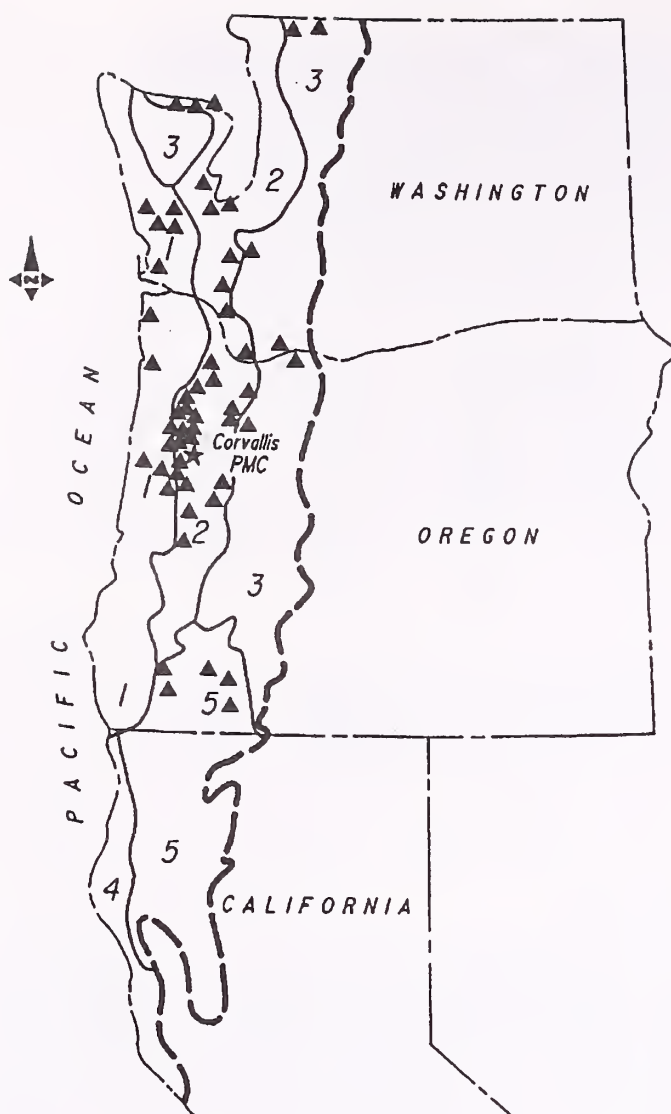
Figure 2—Collection sites for Pacific serviceberry (*Amelanchier alnifolia* var. *semi-integrifolia*). Note: Eighteen accessions not shown. Numbers indicate USDA SCS Major Land Resource Areas.

appearance were rated visually on a scale from 1 to 9, with 1 being excellent, and 9 poor. Uniformity, also visually rated, was recorded in 1990.

Results

Accessions 9028855, 9028859, and 9028862, collected in Yamhill County, OR, Grays Harbor County, WA, and Tillamook County, OR, respectively, have been identified as the top three performers. Selection criteria included vigor, uniformity, height, canopy width, basal width, first-year and following-years growth rates and lateral spread, stem density, fruit production, foliage appearance, and average dates of bud break and leaf drop. These accessions placed in the top 10 percent in eight, eight, and seven of 13 selection criteria, respectively (table 2). Accessions 9028869, 9028860, 9028858, and 9028867 placed in the top 10 percent in at least four of 13 criteria (table 2). Overall, accessions were quite variable in terms of height, canopy width, growth rate, lateral spread, and basal width (table 2). Less variability was observed within accessions.

OCEANSPRAY

Oceanspray is a deciduous shrub known for its value in conservation and ornamental plantings (Antieau 1987). It is found naturally from coastal southern California, north to British Columbia and east to western Montana, Idaho, and northeastern Oregon. In the Pacific Northwest, this species is abundant along the immediate coastline, on the banks of creeks, in the understory of moist woods, and on cutover timberland from sea level to 2,150 m (Hitchcock and others 1961; USDA Forest Service 1988). Habitats vary widely, from climax forests with moist, deep soils to droughty timbered or talus slopes composed of sandy, gravelly, or rocky soils (Antieau 1987; Franklin and Dyrness 1973; USDA Forest Service 1988).

This shrub is 1-6 m in height at maturity, with ovate, toothed leaves, slender, arching branches, and grayish-red bark that exfoliates with age (Hitchcock and others 1961; Munz 1973; Rehder 1940). Pendulous clusters of creamy-white, perfect flowers bloom by midsummer; a small, light-yellow achene matures in fall (Clark 1976; USDA Forest Service 1974; Van Dersal 1942).

Oceanspray contains significant morphological and presumed genetic variation. Natural variation correlates to climate differences and could suggest wide differences in physiological traits (Antieau 1986, 1987). The chromosome number is $n = 18$ (Goldblatt 1979). Insects are the most likely method of pollination.

Seed must either be fall sown or undergo a period of cold-moist stratification at 4 °C for 15-18 weeks, immediately after collection. Vegetative propagation can be accomplished by taking flowerless softwood cuttings from August through September and treating them with a hormone, or by layering. However, success varies widely between clones (Antieau 1987). According to MacDonald (1986), rooting of leafless hardwood cuttings has been achieved by using a cold frame and by precallusing in straw bale bins. The straw bales insulate the 15-cm cuttings, which are packed vertically into a medium of sand and peat after being treated with 0.8 percent IBA powder.

Readily grazed by big game animals such as deer and elk, oceanspray can be important for wildlife habitat improvement (USDA Forest Service 1988). Its ornamental potential, especially its unique flowering and branching, has long been recognized (Rehder 1940; Van Dersal 1942). Furthermore, the species' overall hardy nature, including tolerance to wide moisture regimes, sun or shade, and many soil types makes it useful not only for landscaping, but for low-maintenance riparian plantings, reclamation of droughty and rocky or disturbed sites, windbreaks, and screens. In addition, few pest or disease problems have been reported (Antieau 1987). However, oceanspray is susceptible to fire blight and sensitive to sulfur dioxide (Sinclair and others 1987). A fungal leaf spot (*Septogloeum* sp.) was identified on seedlings growing in the field at the Corvallis PMC.

The goal of this study is to evaluate the variability among populations of oceanspray, select one or more seed sources or clones, conduct propagation, establishment, and adaptation trials, and release a cultivar for commercial production. Target date for completion is 1998. Evidence of wide morphological and genetic variation should provide ample opportunity for improvement (Antieau 1986, 1987).

ACC. #	SURV	HT	GR	GRO	CW	LS	LSO	V	SD	BY	FP	BDBK	LFDP	FA	BW
9028855	100	305	35	258	277	16	254	2	4	86	7	3/23	10/09	5	24
9028859	100	326	55	256	277	22	247	2	5	85	7	3/23	9/27	5	34
9028862	83	317	32	273	207	14	187	1	3	85	7	4/06	10/09	5	34
9028869	83	280	13	252	244	12	224	2	4	86	5	3/23	10/29	7	24
9028860	100	326	26	285	253	11	234	2	4	86	7	4/06	10/29	5	30
9028858	100	314	45	255	262	18	237	2	4	86	7	3/23	9/27	7	37
9028867	100	253	44	199	229	28	196	3	5	85	7	3/23	10/29	5	21
Grand mean	95	254	27	214	199	15	176	3	4	—	8	—	—	6	26
Range	67	186	2	140	140	0	125	1	3	85	5	3/23	9/27	5	15
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	100	351	55	308	317	28	296	5	5	86	9	4/19	10/29	7	43

[1]Ratings: 1 = best; 9 = worst.

Methods

Assembly of oceanspray was conducted in August-September 1987 by Corvallis PMC personnel. Sixty-seven populations were sampled from native stands in western Oregon, western Washington, and northwestern California (fig. 3). Collections came from elevations between 10 and 1,643 m within a precipitation range of 457-2,670 mm.

All seed lots were cold stratified at 4 °C in moist sand for 4 months (December-March). Germination occurred in shallow flats after 16-30 days at a minimum greenhouse temperature of 21 °C. Seedlings were periodically fertilized and drenched with fungicide, then transplanted into 164-mL³ containers when 2 months old. Stock was grown and overwintered in a lathhouse until outplanted as 1-0 stock at the Corvallis PMC on March 24, 1989. The bed consisted of 1.1-m-wide rototilled strips within a field of sheep fescue (*Festuca ovina* var. *ovina*) sod. Experimental design is a randomized incomplete block with five replications. Each plot contains four shrubs spaced 1.5 m within and 3 m between rows. The study site was irrigated twice and received 9 kg of nitrogen in the spring of 1989 for establishment purposes.

Chemical and mechanical means have been used for weed control. The soil type is a deep, well-drained Willamette silt loam with 0-3 percent slopes. Climatic conditions are the same as the Sitka alder study site. Quantitative and qualitative performance data will be collected for 7 to 9 years.

Results

Forty-six accessions are surviving in the common garden nursery at Corvallis. There already appears to be extreme morphological variability both between and within populations, in terms of form, certain leaf characteristics, growth rate, and flower abundance. Individual plants were measured for height and canopy width and visually scored for stem density, vigor, foliage appearance, and flower abundance in 1990. Results for the top five accessions as well as grand means and ranges for all populations are shown in table 3.
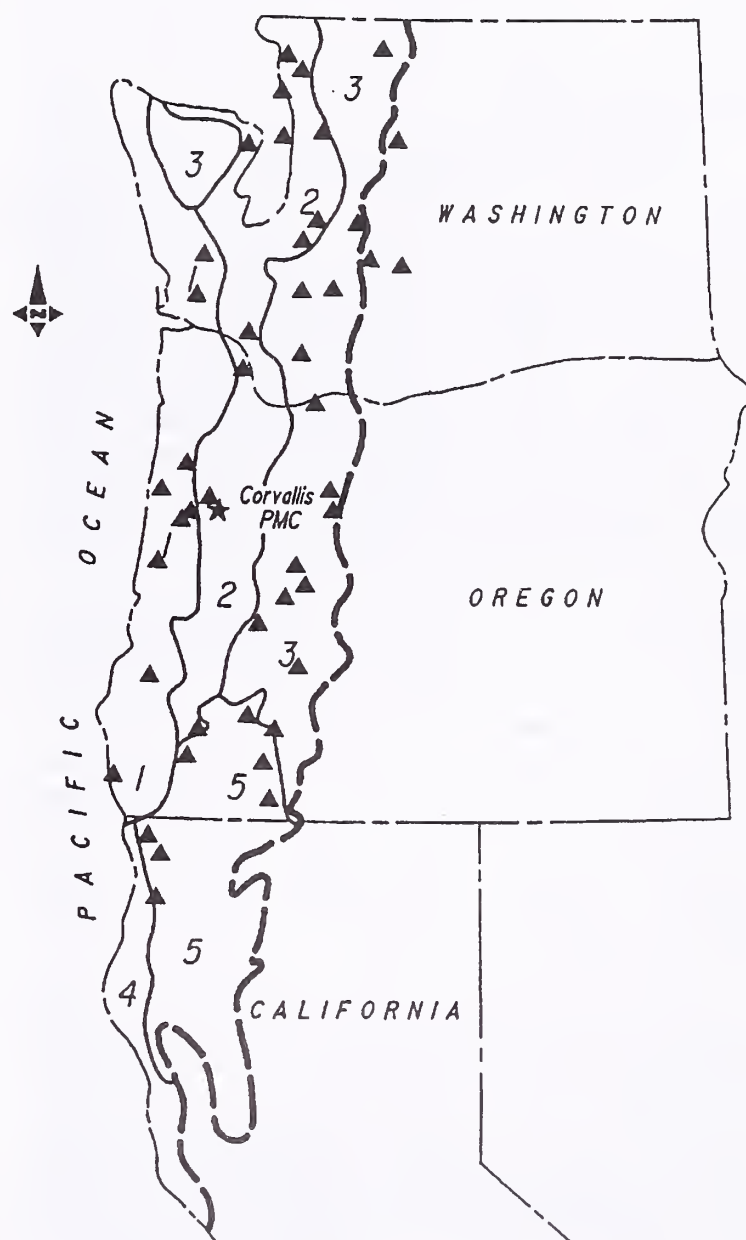

Figure 3—Collection sites for 46 surviving accessions of oceanspray (*Holodiscus discolor*). Note: Numbers indicate USDA SCS Major Land Resource Areas.

159

ACCESSION	ORIGIN	SURVIVAL	HT	CW	SD	V	FA	FL	BY
9047302	Island Co., WA	85	119	98	1	1	3	9	90
9047307	King Co., WA	100	134	104	3	1	4	8	90
9047316	Island Co., WA	90	128	107	2	2	4	8	90
9047323	Curry Co., OR	85	125	88	2	2	5	7	90
9047340	Cowlitz Co., WA	95	134	107	2	1	4	8	90
Grand mean		79	101	75	4	3	4	8	—
Grand range		25	55	34	6	5	6	9	—
		—	—	—	—	—	—	—	
		100	134	128	1	1	3	6	

[1]Ratings: 1 = best; 9 = worst.

VINE MAPLE

Vine maple is a large deciduous shrub or small tree native to an area from northern California to southern British Columbia. While most prevalent west of the Cascade Mountains, it is also found in drier regions east of the Cascade divide, including the Wallowa Mountains of Oregon and interior British Columbia (Anonymous 1976a; Elias 1980; Randall and others 1981). This species occurs along streambanks, in the understory of subclimax forests, and on moist slopes or alluvial bottomlands from sea level to 1,500 m. Other habitats include forest clearings, logged-over areas, talus slopes, rock outcrops, and steep-sided canyons (Anderson 1969; Anonymous 1976a; Franklin and Dyrness 1973; USDA Forest Service 1988).

Vine maple typically grows 1-8 m tall but can attain a height of 12 m on certain sites (Elias 1980; Rehder 1940; USDA Forest Service 1988). In dense shade this plant will often have a twisted trunk, irregular crown, or reclining, vinelike appearance. Specimens grown in the open are more symmetrical, compact, and upright (Anonymous 1976a). While good seed crops are produced in some years, seedlings are rare, even in clearcuts. Exposed mineral soil is required for seed germination. Natural regeneration and downslope colonization is primarily by layering of arching or low-lying branches. The crowns readily resprout after logging or fire (Anderson 1969).

Leaves are opposite and palmately shaped with five to 11 lobes (Munz 1973). Flowers appear in spring as umbellike, drooping clusters when the leaves are half developed; they are polygamous with only one functioning sex per flower (Sargent 1981). Horizontal, two-winged samaras ripen in early fall. The bark is smooth and reddish-brown or grey, while the twigs are green to reddish-brown (Little 1980). Vine maple's chromosome number is $n = 13$ (Hitchcock and others 1961).

Propagation is best by seed. The samaras should be collected when the wings are green and should not be allowed to dry out (MacDonald 1986; Vertrees 1975). Seed must be cold-moist stratified for 90-180 days at 3-5 °C (Dirr and Hueser 1987; USDA Forest Service 1974; Vertrees 1975). When unstratified seed is to be fall sown in the field, cracking the hull (pericarp) can improve spring germination.

Cuttings are difficult to root. While layering is more viable, both are very slow. Grafting success for vine maple is much higher on Japanese maple (*Acer palmatum*) rootstock than its own (Dirr and Hueser 1987; Vertrees 1975). If cuttings are to be employed, "half-ripened greenwood" taken in summer has worked in some cases. Budding has also been employed (Anonymous 1976a).

Maples in general are host to numerous pests (Dirr 1983). Some common diseases reported on vine maple include various leaf spots, powdery mildew, coal canker (*Hypoxylon mediterraneum*), and tar spot (*Rhytisma punctatum*) (Anonymous 1976a; Sinclair and others 1987). Insect pests include cottony maple scale (*Pulvinaria innumerabilis*) and many defoliating moths (Anonymous 1976a).

The wildlife value of vine maple is high. Leaves and twigs are important food for elk, mountain beaver, and deer (USDA Forest Service 1988; Van Dersal 1938). The seed is eaten by squirrels and other small mammals, as well as by game and songbirds (Little 1980).

Like many species in the Aceraceae family, vine maple is known for its ornamental value: in this case the bright orange-red fall foliage, rose-colored fruits, attractive flowers, and contorted growth form (Anonymous 1976a). Four cultivars are recognized: 'Monroe,' 'Little Gem,' 'Glen Del,' and 'Elegant' (Vertrees 1979). However, these ornamental types were not selected for traits important for reclamation plantings.

Vine maple's natural adaptation to streambanks, tolerance to sun or shade and a range of soil moisture regimes, wildlife value, and vigorous, fibrous root system make the species an excellent candidate for riparian restoration within the region (Anonymous 1976a). Also, its ability to layer improves the potential for erosion control. This trait, along with other factors such as form and growth rate, are useful selection criteria.

Methods

In September-October 1989, fifty populations of vine maple were sampled from western Oregon, western Washington, and northwestern California (fig. 4). Collections originated from elevations between 18 and 1,128 m within a precipitation zone of 762-4,064 mm. As seed was stripped from the trees, it was immediately placed into plastic bags filled with moist peat moss and sealed to prevent dehydration.

All seed lots were cold stratified in moist peat at 4 °C for 6 months (October-March). In March, seed was planted near the surface in shallow flats, placed under a greenhouse mist system, and periodically drenched with a fungicide and fertilizer. Germination success was highly variable, but all 50 lots produced viable plantlets. Seedlings were then transplanted into 164-mL containers in May and moved into a lathhouse by mid-June. The rooting media contained a slow-release fertilizer.

As an alternative, seed of each lot was sown directly into containers in October 1989 and allowed to overwinter in a lathhouse. Seventy-five percent of the accessions germinated in the spring of 1990 using this method. Additional seedlings emerged for certain lots in the spring of 1991. For all sources, seedlings grew very slowly the first year, with most

plants ending the growing season 2.5-7.5 cm tall. Leaf spot (*Septoria* sp.) became severe in the lathhouse by fall, contributing to leaf senescence.

To improve plant size and root development, all 1-0 stock was transplanted into 3.5-L plastic liners in March 1991, and an attempt was made to inoculate with endomychorrizae. Rooting media contain 10 percent soil obtained from a natural stand of vine maple. Results of this procedure are not yet known.

Currently, stock is being grown under lathhouse conditions with supplemental water and fertilizer. Two-year-old plants will be outplanted near Corvallis, OR, into strips of chemically killed sod during the spring of 1992. Experimental design will be a randomized block with five replications of four plant plots. Data similar to previous studies will be collected and propagation methods evaluated through 1999.

SUMMARY AND FUTURE RESEARCH

Seed source or provenance studies of three native, deciduous shrubs: Sitka alder, Pacific serviceberry, and oceanspray are in progress at the Corvallis PMC, OR. Forty-six to 72 populations of each are being compared for morphological traits such as growth rate, fruit or flower abundance, vigor, foliage appearance, phenology, and form. In addition, a fourth study with 50 accessions of vine maple will be planted in 1992.

During the 1990's, establishment and propagation technology, including tissue culture, stock type, and inoculation requirements, will be investigated. Once single-accession or multiple-accession selections are made, they will be increased for further testing of field performance. Promotional plantings are planned with cooperators of Soil and Water Conservation Districts to assist in delineating area of adaptation. Finally, when seed sources or clones are proven successful, they will be released as cultivars for commercial production.

REFERENCES

Anderson, H. G. 1969. Growth form and distribution of vine maple (*Acer circinatum*) on Marys Peak, western Oregon. Ecology. 50(1): 127-130.

Anderson, H. G.; Bailey, A. W. 1980. Effects of annual burning on grassland in the aspen parkland of east-central Alberta. Canadian Journal of Botany. 58: 985-996.

Anonymous. 1976a. *Acer circinatum* Pursh vine maple. Davidsonia. 7(3): 32-37.

Anonymous. 1976b. *Amelanchier alnifolia* (Nuttall) Nuttall saskatoon. Davidsonia. 7(1): 5-13.

Antieau, C. J. 1986. Patterns of natural variation in oceanspray (*Holodiscus discolor*) (ROSACEAE). HortScience. 21(3): 120.

Antieau, C. J. 1987. Field notes: *Holodiscus discolor*. American Nurseryman. 166(2): 110.

Binkley, D. 1982. Nitrogen fixation and net primary production in a young Sitka alder stand. Canadian Journal of Botany. 60: 281-284.

Binkley, D.; Lousier, J. D.; Cromack, K., Jr. 1984. Ecosystem effects of Sitka alder in a Douglas-fir plantation. Forest Science. 30(1): 26-35.

Bishop, B. H.; Nelson, S. H. 1980. Propagation and transplanting of saskatoon (*Amelanchier alnifolia* Nutt.)

Figure 4—Collection sites for vine maple (*Acer circinatum*). Note: Numbers indicate USDA SCS Major Land Resource Areas.

softwood cuttings. Canadian Journal of Plant Science. 60: 883-890.

Bollen, W. B.; Lu, K. C.; Trappe, J. M.; Tarrant, R. F. 1969. Influence of Sitka alder on soil formation and microbiological succession on a landslide of alpine origin at Mount Rainier. Res. Pap. PNW-103. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 5 p.

Carlson, J. R. 1979. Streamside vegetation. Tech. Note 55. Portland, OR: U.S. Department of Agriculture, Soil Conservation Service. 9 p.

Clark, L. J. 1976. Wildflowers of the Pacific Northwest from Alaska to Northern California. Vancouver, BC: Evergreen Press. 245 p.

Cwynar, L. C. 1987. Fire and the forest history of the north Cascade range. Ecology. 68(4): 791-802.

Dirr, M. A. 1983. Manual of woody landscape plants. Champaign, IL: Stipes Publishing. 826 p.

Dirr, M. A.; Heuser, C. W., Jr. 1987. The reference manual of woody plant propagation. Athens, GA: Varsity Press. 239 p.

Elias, T. S. 1980. The complete trees of North America. New York: Van Nostrand Reinhold. 948 p.

Franklin, J. R.; Dyrness, C. T. 1973. Natural vegetation of Oregon and Washington. Gen. Tech. Rep. PNW-8. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 417 p.

Goldblatt, P. 1979. Miscellaneous chromosome counts in Angiosperms. II. Including new family and generic records. Annals of Missouri Botanical Gardens. 66: 856-861.

Harrington, C. A.; Deal, R. L. 1982. Sitka alder, a candidate for mixed stands. Canadian Journal of Forest Research. 12(1): 108-111.

Heilman, P. 1983. Effects of surface treatment and interplanting of shrub alder on growth of Douglas fir in coal spoils. Journal of Environmental Quality. 12(1): 109-113.

Hibbs, D. E. 1986. Managing red alder. Extension Circ. 1197. Corvallis, OR: Oregon State University Extension Service. 8 p.

Hitchcock, C. L.; Cronquist, A.; Ownby, M.; Thompson, J. W. 1961. Vascular plants of the Pacific Northwest. Part 3: Saxifragaceae to Ericaceae. Seattle, WA: University of Washington Press. 614 p.

L. H. Bailey Hortorium. 1976. Hortus third. New York: Macmillan. 1290 p.

Little, E. L. 1980. The Audubon Society field guide to North American trees, western region. New York: Alfred A. Knopf. 639 p.

MacDonald, B. 1986. Practical woody plant propagation for nursery growers. Vol. 1. Portland, OR: Timber Press. 669 p.

Marks, J. S.; Marks, V. S. 1988. Winter habitat use by Columbian sharp-tailed grouse in western Idaho. Journal of Wildlife Management. 52(4): 743-746.

Miner, C. L. 1990. Changing times for hardwoods. Forestry Research West. Fort Collins, CO: U.S. Department of Agriculture, Forest Service; December 1990: 1-6.

Molina, R. 1981. Ectomycorrhizal specificity in the genus *Alnus*. Canadian Journal of Botany. 59(3): 325-334.

Munz, P. A. 1973. A California flora and supplement. Berkeley and Los Angeles, CA: University of California Press. 1681 p. and 224 p.

Nelson, S. H. 1987. Effects of stock plant etiolation on the rooting of saskatoon berry (*Amelanchier alnifolia* Nutt.) cuttings. Canadian Journal of Plant Science. 67: 299-303.

Nelson, S. H.; Bishop, B. H. 1980. Rootstock studies on saskatoons (*Amelanchier alnifolia* Nutt.). Canadian Journal of Plant Science. 60: 879-882.

Olson, A. R. 1984. Structural aspects of pollination in *Amelanchier alnifolia* (Maloideae). Canadian Journal of Botany. 62(4): 858-864.

Randall, W. R.; Keniston, R. F.; Bever, D. N.; Jensen, E. C. 1981. Manual of Oregon trees and shrubs. Corvallis, OR: Oregon State University Bookstores: 203-204.

Rehder, A. 1940. Manual of cultivated trees and shrubs hardy in North America, exclusive of the subtropical and warmer temperature regions. New York: Macmillan. 996 p.

Sargent, C. S. 1981. The silva of North America, vol. 2. New York and Boston: Houghton-Mifflin: 93-94.

Sherman, H. 1989. Streambank plants vital to water quality. Agricultural Research. 8: 19.

Sinclair, W. A.; Lyon, H. H.; Johnson, W. T. 1987. Diseases of trees and shrubs. Ithaca, NY, and London: Columbia University Press. 575 p.

Steeves, T. A.; Lehmkuhl, D. M.; Bethune, T. D. 1979. Damage to saskatoons *Amelanchier alnifolia* by the apple curculio, *Tachypterellus quadrigibbus* (COLEOPTERA: Curculionidae). Canadian Entomology. 111(6): 641-648.

Swingle, C. F. 1939. Seed propagation of trees, shrubs, and forbs for conservation plantings. SCS-TP-27. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 198 p.

Tremblay, F. M.; Lalonde, M. 1984. Requirements for in vitro propagation of seven nitrogen-fixing *Alnus* species. Plant Cell Tissue Organ Culture. 3: 189-199.

U.S. Department of Agriculture, Forest Service. 1971. Diseases of forest and shade trees of the United States. Agric. Handb. 386. Washington, DC: U.S. Department of Agriculture, Forest Service. 658 p.

U.S. Department of Agriculture, Forest Service. 1974. Seeds of woody plants in the United States. Agric. Handb. 450. Washington, DC: U.S. Department of Agriculture, Forest Service. 883 p.

U.S. Department of Agriculture, Forest Service. 1988. Range plant handbook. Mineola, NY: Dover Publications. 816 p.

Van Dersal, W. R. 1938. Native woody plants of the United States: their erosion control and wildlife values. Misc. Publ. 303. Washington, DC: U.S. Department of Agriculture. 362 p.

Van Dersal, W. R. 1942. Ornamental American shrubs. New York: Oxford University Press: 216-217.

Vann, A. R.; Brown, L.; Chew, E.; Smith, G. D.; Miller, E. 1988. Early performance of four species of *Alnus* on derelict land in the industrial Pennines. Quarterly Journal of Forestry. 82(3): 165-170.

Vertrees, J. D. 1975. Observations on *Acer circinatum* Pursh propagation. Plant Propagator. 21(4): 11-12.

Vertrees, J. D. 1979. Notes on variants of *Acer circinatum* Pursh. In: 1978 Yearbook. London: International Dendrology Society: 82-84.

Weber, G. P.; Wiesner, L. E.; Lund, R. E. 1982. Improving germination of skunkbush sumac and serviceberry seed. Journal of Seed Technology. 7(1): 60-71.

PLANTING TECHNIQUES FROM THE ABERDEEN, ID, PLANT MATERIALS CENTER FOR VEGETATING SHORELINES AND RIPARIAN AREAS

J. Chris Hoag

ABSTRACT

The Aberdeen Plant Materials Center found the following woody riparian species effective in shoreline protection and revegetation of eroded stream channels: coyote willow (Salix exigua), dwarf blue arctic willow (Salix purpurea nana), laurel willow (Salix pentandra), prairie willow (Salix humilis), 'Siouxland' eastern cottonwood (Populus deltoides), 'Imperial' Carolina poplar (Populus canadensis), and robust poplar (Populus robusta). Small power augers were the most effective planting method. Hormones, fungicides, and fertilizer did not necessarily enhance survival and establishment. Long cuttings with large diameters planted into the midsummer water table gave the highest success rate.

INTRODUCTION

The Plant Materials Center (PMC) at Aberdeen, ID, is one of 26 PMCs in the United States run by the Soil Conservation Service, U.S. Department of Agriculture. Even though we are located in Idaho, our service area includes southern Idaho, southeastern Oregon, the northeast tip of California, most of Nevada, and Utah. The Aberdeen Plant Materials Center was established in 1939 to assemble, test, and release plant materials for conservation uses; determine techniques for their successful use; provide for their commercial increase; and promote the use of plant materials needed to meet the objectives and priorities of the National Conservation Program.

One priority in Aberdeen's Long Range Plan is the development and release of new plants for use in protecting shorelines and revegetating riparian areas. We have been working with the Bureau of Reclamation (BOR), U.S. Department of the Interior, to develop a vegetative solution for erosion around American Falls Reservoir in southeastern Idaho, and, more recently, working in Nevada on revegetating an eroding section of a perennial stream called Trout Creek.

PROBLEM

American Falls Reservoir was built on the Snake River in 1926 to store irrigation water for farmers and ranchers downstream of the dam. The reservoir's capacity is 1,700,000 acre-feet. The elevation of the reservoir is about 4,350 feet. The annual precipitation for this area is 8-10 inches. Idaho Power has hydroelectric turbines in the dam for power generation. The general operation of the reservoir is based on the irrigation needs of the water-right owners below the dam. Drawdown starts in April and continues during the summer until the end of the irrigation season, which is usually in October. The water level in the reservoir decreases continuously over the course of the summer according to irrigation water demand downstream. The reservoir is refilled during winter and spring.

The main problem at American Falls Reservoir is that much of the shoreline soils are clay and sand. Many shorelines have been eroded into 20- to 40-foot vertical cliffs. Wind-driven waves during the spring refill and summer drawdown slam against the vertical cliffs causing massive undercutting and sloughing. In some cases, the shoreline has retreated hundreds of feet with the loss of many acres of valuable farmland. Social, political, and economic reasons have prompted BOR to come up with some method of controlling this erosion. Their answer is to armor the shoreline with Geotextile sheet and rock riprap. Considering that the reservoir is about 25 miles long, and much of the shoreline needs protection, the cost of riprapping the shoreline on both sides of the reservoir at $30 to $40 per linear foot is prohibitively expensive. Other methods of protecting the eroding shorelines must be found.

In 1986, the Aberdeen PMC entered into an agreement with BOR to study methods of establishing protecting vegetation along the shoreline of American Falls Reservoir. The objectives of the study were: (1) test various plants for their erosion controlling ability along the shorelines (including unprotected stretches and stretches partially or fully protected by structures), (2) perfect low-cost, high-volume planting techniques, (3) ensure low maintenance costs, and (4) keep in mind wildlife and fish habitat needs, in addition to esthetic values.

The study is composed of two parts. The initial study was started in 1986 and lasted for about 2 years. All subsequent years of the study and our current work at Trout Creek incorporate and build on the techniques and species that were developed in the first 2 years of the study.

MATERIALS AND METHODS

The Aberdeen PMC has been testing riparian woody species since 1982. A large planting of various windbreak species was established in 1982. It contains, among other things, about 70 different riparian accessions. A willow

planting was established in 1984. It includes about 30 different accessions of willows. These accessions were collected from native stands throughout the Aberdeen PMC service area and from PMCs in North Dakota, Montana, Washington, and Michigan. From these two initial trials, 15 different accessions were selected for advanced testing (table 1).

Site

American Falls Reservoir is an extremely harsh site because of three major limiting factors. The first major limiting factor at the reservoir is the soil. It is made up of clays and silty clays intermixed with layers of sand. It is very compacted and has almost no organic soil nutrients. This makes root penetration very difficult. In addition, as the soils dry out during drawdown, the sand, shattered clay, and silts would fill up the hole as fast as the drill instrument was removed.

Another major limiting factor is the lack of natural vegetation. Only a limited number of species are available at the reservoir to establish, spread, and protect the shoreline. These species are normally found only in protected areas or areas that have extra water seepage from springs or summer irrigation water that drains underground from the fields above the reservoir.

The last major limiting factor is the irrigation drawdown of the water stored in the reservoir. From the start of the irrigation season in mid-April to the end of the irrigation season in late October, the water in the reservoir is drawn down to as low as 10 percent (or less) of its capacity. This means that willows planted along the shore are 1,000 feet or more from water by the end of the season. After the irrigation season, the headgates are closed and the reservoir is refilled. The last 10 vertical feet of the reservoir are filled by March or April. This means that willows planted at the base of the shoreline are inundated just before they break bud and stay inundated until June or July.

American Falls Reservoir lies generally southwest to northeast. Prevailing winds are from the southwest and are most active in the early spring. Test plots were established on five different beaches around the reservoir. Of the five beaches, three beaches are unprotected and face east, west, and south. The unprotected beaches are bounded by vertical cliffs at the high-water line, and fairly uniform slopes drop away from the cliffs at 3 to 5 percent. The other two beaches are protected by structures, such as rail and wire, rail and tire, rock riprap, and tire mattresses. Willows were planted in front of them. These structures generally extend 40 to 60 feet out from the cliffs. One of the beaches faces east and the other faces west.

Test Design

The test plots were set up in randomized, replicated complete blocks. Initially, each block contained all of the accessions in a test and extended out from the cliff at three different inundation levels. At each inundation level, treatments were randomized. Each combination of inundation level, accession, and treatment was replicated three times. The accessions were planted with five members spaced 1 foot apart in a "W" arrangement. This allowed not only an adaptation test, but was also thought to provide the best protection possible for the shoreline. As the survivability of the different accessions became established, the "W" arrangement was supplemented by various other arrangements based on the individual growth types of the accessions. For all succeeding tests, accessions were planted in five groups of four individuals randomly arranged in the various segments of the block.

Generally, we tried to use the natural growing habits of the willows when designing the layout of the tests. Creeping-type willows with their flexible stems and extensive root systems, shrub-type willows with shorter stature and somewhat flexible stems, and tree-type willows with large roots and trunks were planted in association with each other in a way that wave energy would be reduced as it went through each successive type before it impacted the cliff or structure.

Table 1—Species selected for advanced testing from two initial trials at the Aberdeen PMC

Accession	Scientific name	Common name	Source
9005049	*Salix pentandra*	Laurel willow	Michigan
9047349	*Salix vitellini*	Golden willow	North Dakota
9044859	*Salix alba*	White willow	North Dakota
9053849	*Salix fragilis*	Brittle willow	Idaho
9020059	*Salix drummondiana*	Drummond willow	Washington
9020121	*Salix lemonii*	Lemon willow	Washington
9020100	*Salix rigida* var. *mackenziana*	Mackenzie willow	Washington
303584	*Salix humilis*	Prairie willow	North Dakota
9026075	*Salix exigua*	Sandbar willow	Montana
9020099	*Salix exigua*	Sandbar willow	Washington
9044861	*Salix exigua*	Sandbar willow	Idaho
9031690	*Populus robusta*	Robust poplar	North Dakota
9031688	*Populus deltoides*	'Siouxland' cottonwood	North Dakota
432347	*Populus* x *canadensis* (*deltoides* x *nigra*)	'Imperial' Carolina poplar	Michigan
9005050	*Salix purpurea nana*	Dwarf blue arctic willow	Michigan

Test Methods

Initially, to perfect low-cost, efficient, successful planting techniques, five different factors were examined. They were: (1) planting methods, (2) cutting diameter, (3) cutting length, (4) planting depth, and (5) planting supplements. To test these factors, five different accessions were used that grew on different areas of the reservoir as native or naturalized species, or that were species that are widely used and well adapted to the area. In subsequent years, after establishing which factors improved the planting success, stored versus fresh cuttings and more species were examined.

Planting Methods—Six treatments were tested: Direct insertion by hand, direct insertion by pounding with a small sledgehammer onto a special shock-absorbing cover, a 1.5-inch-diameter hand auger, and a 1-inch-diameter planting bar. In subsequent years, a 3-inch-diameter, two-person power auger and a 3-inch-diameter, towable one-person power auger were tested. The compacted nature of the clay soils meant an aggressive method was needed to get the cuttings into the ground.

Cutting Diameter—Cutting diameter varied greatly by species. Six classes of diameters were established: 0.125-0.25, 0.25-0.5, 0.5-0.75, 0.75-1.0 inch, 1.0-1.5 inches, and greater than 1.5 inches. All diameter classes were represented by all the accessions tested except the dwarf blue arctic and the sandbar willows, which rarely get bigger than 0.25-0.5 inch. In subsequent years, "dormant stump" plantings were made where the cutting diameters ranged from 2 to 5 inches in diameter.

Cutting Length—Cutting length also varied greatly by species and source. The majority of the first plantings were 18 inches long. Specific tests were made of 1-foot, 2-foot, and 3-foot lengths. Generally, only about 6 to 10 inches of the cutting protruded from the soil after planting. Subsequent years' tests were made of 8 to 12 foot lengths. This was to ensure that enough stem protruded above the ground after planting so that the tops were above the high waterline.

Planting Depth—Planting depth varied with the planting method. The cuttings were placed so that at least one to three buds were above ground level. Generally, wherever it was possible, two-thirds of the cutting was placed into the ground. Direct insertion by hand was the shallowest method, about 3 to 6 inches, with a few cuttings going as deep as 8 to 10 inches. The hand auger and bar generally put the cuttings down about 12 inches. The power augers put the cuttings down anywhere from 24 to 34 inches depending on the compacted soil layers. With an extension, the one-person towable auger could go deeper than 36 inches.

Planting Supplements—Planting supplements were examined to see if they would enhance survival and rapid establishment, which would in turn decrease the total cost per plant. About 50 gm of Ozmacote 19-6-12 time-release fertilizer was placed 3 inches below the cutting in a hand-augered hole and covered with a layer of soil. Two treatments, fertilizer and no fertilizer, were applied to each of four different accessions. Four treatments with a rooting hormone, fungicide, both, and neither were also tested.

The rooting hormone was 0.1 percent indole-3-butyric acid. The fungicide was 4.0 percent Thiram. They were applied as dry powder dips or as liquid dips just prior to planting according to the manufacturer's recommendations. Finally, soaking the stored cuttings for 24 to 48 hours in tap water versus planting dry cuttings was tested.

Adaptation Trial—Over 14 different accessions from Washington, Oregon, Montana, Utah, Idaho, North Dakota, and Michigan were tested to see what their range of adaptability was. These cuttings were arranged in rows that contained 10 cuttings of a single accession with each accession randomly replicated three times along the beach. The rows were planted at a 45-degree angle to the cliff. The rows were 2 feet apart, and the cuttings were 3 feet apart within the row.

Stored versus Fresh Cuttings—Large-diameter cuttings were harvested from dormant plants in late winter. The cuttings were then placed in a walkin cooler that was set at 35 to 39 °F. The cutting date was documented in the files. Large-diameter fresh cuttings were harvested within 20 hours of planting. Both stored and fresh cuttings were harvested from the same parent plant. All cuttings were 1.5 inches or larger. All cuttings were planted 26 to 34 inches deep. After planting, they had 2 to 6 feet of stem above the ground.

RESULTS AND DISCUSSION

Of the four planting methods initially tested, direct insertion by hand was the most successful. It was followed closely by the hand auger and the planting bar. The direct insertion by pounding tended to shatter the tops of the cutting, even though a special metal pipe cover with a piece of rubber belting was placed in the top to absorb some of the force generated by the sledgehammer. This method was used only once and then it was discontinued.

Close contact between the surface of the cutting and soil was established as a critical element. Removal of extra soil from the hole, which necessitated backfilling, was determined to be too time consuming to be practical in a large-volume planting.

For the most part, the four different planting methods rarely placed the cuttings any deeper than about 12-14 inches. Excellent sprouting success was obtained the first summer with these methods. However, by the following summer, after a normal windy spring with abundant wave action, most of the cuttings had either been ripped out of the soil entirely or the soil was washed away from the roots down to about 8-10 inches. It was apparent that the cuttings had grown a good root system over the initial summer growing season with some of the roots measuring over 26 feet long. Even with this kind of root system, in order to survive at the reservoir, the cuttings were going to have to be planted much deeper.

The best sprouting success was achieved when the cuttings were larger than 0.5 inch in diameter. The only willow that did not show this success was the dwarf blue arctic willow. No matter what was done to the cuttings, sprouting success was always low for some reason. However, its size, shape, flexible stems, and esthetic appeal are nearly perfect for a first row of willows. So we continued to test it to

see if the right combination of sprouting factors could be found. Rooted stock worked well in all subsequent tests.

Once it was determined that the diameter should be greater than 0.5 inch, much larger diameter cuttings were tested. In subsequent years, it became apparent that cuttings no less than 1 inch and preferably larger than 1.5 inches in diameter produced the best sprouting success. "Dormant stumps" were also used with a diameter of 3 to 5 inches. These diameter sizes appear to have a much better supply of stored energy than the smaller diameters, so they can survive a longer sprouting period. They also can withstand much greater wave velocities than can the smaller diameters.

The 18-inch length of the initial cuttings was determined to be much too small after the first 2 years. This was because: (1) they could not be planted deep enough to keep the waves from washing them out, (2) they could not be planted deep enough to reach the midsummer water table, and (3) the tops were not long enough to be above the water line when the reservoir was full.

Even with roots that measured over 26 feet long, the cuttings were ripped out of the soil or the soil was washed away from the roots down to 8 to 10 inches. It was felt that overall survival could be increased if the cuttings were not totally inundated during initial bud break, not to mention late spring and early summer growing periods. In addition, the purpose of the cuttings was to decrease the wave energy, but with the 18-inch length, the cuttings were well under the high-energy sections of the waves.

After reaching this decision, power augers were tested. It was clear that the other methods, even though they were fast and efficient, were not going to get the cuttings deep enough to allow them to survive at American Falls Reservoir. Tractor-mounted power augers or any other vehicle-mounted equipment could not be used at the reservoir because of the soils. If they were the least bit wet, any heavy piece of equipment would mire down in a very short period of time. Handheld power augers, in the size necessary to get through some of the hardpan areas, were too large and cumbersome to efficiently plant large numbers of cuttings with a reasonably sized planting crew. The towable auger was an attempt to increase the number of cuttings that could be planted over long distances and with a reasonably sized crew. Both power augers had establishment rates that were equal to the hand augers.

Cutting lengths of 8 to 12 feet had excellent sprouting success because of two factors. First, the cuttings could

be planted 32 to 36 inches deep, and second, they extended 3 to 5 feet above the high water. The only major problem was with ice. In a normal year, BOR endeavors to stop raising the level of the reservoir once thick ice has formed on the surface. When the ice does form, it freezes around the trunks of the trees and shrubs established along the shoreline and will actually pull them out of the ground. In addition to freezing around the stems, willows planted in front of structures encountered severe damage along the stems from ice chunks that were floating on the surface after breakup. The wind-driven waves would smash them against the willows, which could not give enough because they were planted too close to the structures.

In the planting supplement trial, we could find no clear-cut advantage to using fertilizer, rooting hormones, or fungicides when the cuttings were part of a high-volume, high-intensity riparian planting program. Untreated cuttings had as high or higher establishment success when compared to those that were treated. Data on soaking are not clear-cut in our studies. However, when one reviews the literature with its numerous references to the benefits of soaking, it should be encouraged as a standard practice.

In the stored versus fresh trial, we initially found that 95 percent of the stored cuttings leafed out the first summer, while only 5 percent of the fresh cuttings leafed out. By the following summer, however, 80 percent of the fresh cuttings had leafed out, and all of the stored cuttings appeared dead. We are continuing to examine this problem, but at present we do not have a recommendation to make.

RECOMMENDATIONS

We recommend that, wherever possible, cuttings be at least 1 inch or greater in diameter. They should be long enough to reach the midsummer water table. This is to ensure the cuttings have ample water to sprout. It also puts the majority of the roots below most of the root systems of competing vegetation. The cuttings should also be high enough above ground level to be above the inundation level and to avoid shading from weeds and grass. If erosion control is your objective, the cuttings must be tall enough to intersect wave action. In high-volume, high-intensity planting programs, the use of fertilizer, rooting hormone, and fungicide do not necessarily increase the establishment success to a point where these practices will repay the extra effort and cost associated with them.

USE OF FLOODWATER TO DISPERSE GRASS AND SHRUB SEEDS ON NATIVE ARID LANDS

Jerry R. Barrow

ABSTRACT

Dry stream channels of arid rangelands are typically more fertile and mesic than adjacent slopes. The productivity of these channels is evident by their relatively abundant plant biomass. Substantial down-channel establishment of seeded and native species from root-plowed and seeded strips was observed on the Jornada Experimental Range. There appears to be good potential for using flood water as a low-input method of seed dispersal for subsequent revegetation of natural waterways.

INTRODUCTION

The shrub-grasslands of the arid Southwest have shifted dramatically to shrub-dominated communities in the last 125 years (Buffington and Herbel 1965). This shift has resulted in reduced forage for livestock, reduced ground cover, and accelerated soil loss by wind and water erosion. In addition, desirable habitats for wildlife have been adversely affected (McKell and Garcia-Moya 1989).

Efforts to reverse, or slow, this trend by using specialized grazing systems, mechanical and chemical control of shrubs, or reseeding of desirable plant types have been only moderately successful at best. The costs of improvements of arid lands generally do not justify the required investment given the biological uncertainty of the response to the treatments. For example, plant establishment efforts often fail because of either infrequent and unpredictable rainfall events, soil crusting, poor soils, high incidence of rodents, high ambient temperatures, or one of many other adverse events. Low-input methods that would utilize on-site resources and maintain or increase the productivity, stability, and use of these lands would be very desirable.

GENERAL OBSERVATIONS

As shrubs have increased and grasses decreased, flooding has removed soil and organic materials and redistributed them along the dry channels. The increased fertility and moisture have increased within-channel potential for plant productivity. This is evident by the abundant plant biomass production along the channels as compared to the slopes. Therefore, these channels should be the focus for revegetation efforts. In addition, these desert waterways

provide favorable conditions for continued plant dispersal and establishment.

Rainfall patterns in the arid Southwest are such that approximately 50 percent of the annual precipitation occurs as intense, localized thundershowers from mid- to late summer. Resulting flood water carries seed, silt, and organic material, and deposits them along the stream in areas where the flow is slowed by bends, vegetation, or decreasing slope. The deposited seed may remain moist for several days to a week, meeting favorable conditions for seedling emergence and establishment. Stream transport of the seed may also accomplish scarification and presoaking requirements for germination. Once seedlings emerge along these waterways, they have the greatest opportunity for establishment.

JORNADA OBSERVATIONS

The potential for natural seeding by flood water along dry streambeds was demonstrated by two unrelated activities on the Jornada Experimental Range (JER), located northeast of Las Cruces, NM. Approximately 25 years ago, strips were root plowed perpendicular to the direction of water flow (Herbel and others 1973), where creosote bush (*Larrea tridentata* DC) had invaded a black grama (*Bouteloua eriopoda* [Torr.] Torr.) community on the south boundary of the JER. This is a gentle sloping area fanned with many small gullies.

These plowed strips were seeded with Lehmann lovegrass (*Eragrostis lehmanniana* Nees), Boer lovegrass (*Eragrostis chloromelas* Steud.), black grama, sideoats grama (*Bouteloua curtipendula* [Michx.] Torr.), blue grama (*Bouteloua gracilis* [H.B.K.]), and fourwing saltbush (*Atriplex canescens* [Pursh] Nutt.).

Independent of these events, a natural gas pipeline was constructed across the area, ranging from 50 to 500 meters downstream from the root-plowed areas. This left a small dike less than 12 inches high extending across the area.

RESULTS

Currently, stand establishment of the seeded species ranges from poor to good in five different root-plowed strips upstream from the pipeline. The best original establishment of the seeded species occurred along the gullies within the strips. Downstream establishment of both seeded and native species was observed. We ascertained that the dike from the pipeline caused flood water to slow, allowing the deposition of silt, organic material, and seed. The establishment of these plants enhanced further seed and silt deposition.

Grass and fourwing saltbush communities have expanded laterally and upstream from the dike. This area is composed of good stands of both love grasses, sideoats grama, and fourwing saltbush, as well as plains bristlegrass, (*Setaria leucopila* [Scribn. & Merr.] K. Schum.), a native species. The area above the dike has excellent forage production, vegetative cover, and wildlife habitat. In contrast, creosote bush is the predominant plant below the dike, with bare surface between the plants (see figs. 1 and 2).

It appears that seeds from the root-plowed areas were deposited near the dike. As new plants became established they produced seed and also slowed water coming from upstream for additional silt and seed deposition along the gully. Consequently, gullies were filled with soil and organic material, adding to the fertility and promoting additional establishment of grasses both laterally and along the gully. As this community developed, creosote and tarbush plants have died, likely because of increased competition from the grasses and possibly because of modifications in the subsoil environment (soil moisture, microflora). These changes have slowed water flow and have increased water infiltration, silt, and organic matter deposition, further increasing the fertility and mesic conditions

Figure 1—Plant establishment downstream from root-plowed strips and above dike.

Figure 2—Creosote bush and bare surface just below dike.

along the gullies. It also appears that fourwing saltbush is more competitive with the grass invasion than either creosote or tarbush.

POSSIBILITIES FOR MANAGEMENT

To utilize flood water for dispersing and establishing seedlings, a simple gully seeder was developed. One seeder consisted of a post, placed in the gully, with a vane that would be moved by the water (see fig. 3). This in turn would move a slide covering the mouth of an inverted seed bottle attached to the post. The seed would be dropped into the stream and carried downstream where it could be deposited with silt and organic matter for potential germination and establishment. A second seeder was also tested; it consisted of a steel post with the inverted seed bottle attached with a stopper in the mouth of the bottle. A flexible wire was attached to the stopper and threaded through the eye of a bolt at the base of the post and to an approximately 1-foot section of railroad tie, which would only be moved when sufficient flow provided proper conditions for dispersal and establishment.

These seeders were positioned in small gullies, and approximately 750 gallons of water were pumped into the gully, simulating flood conditions. The bottle was filled with alkali sacaton (*Sporobolus airoides* [Torr.] Torr.), blue panic (*Panicum antidotale* Retz.), and fourwing saltbush seed. The gully was dammed approximately 50 meters downstream to allow for the settling of the silt and water. Brush and debris were added to the surface just above the dike to provide shade and protection to the seed and silt.

Very good germination of the grasses and fourwing saltbush was observed just upstream from the dikes where seed was covered with silt and where the surface was protected by shading. Graveled areas were also good seed beds for germination. However, it is essential for these plants to receive adequate additional moisture for establishment and their development to maturity. These conditions were not met, and all the seedlings died. However, the experiment demonstrated the potential for flood water to disperse and germinate seeds. An additional advantage of the gully seeder is that if they are not activated by flooding the seed can be used another year.
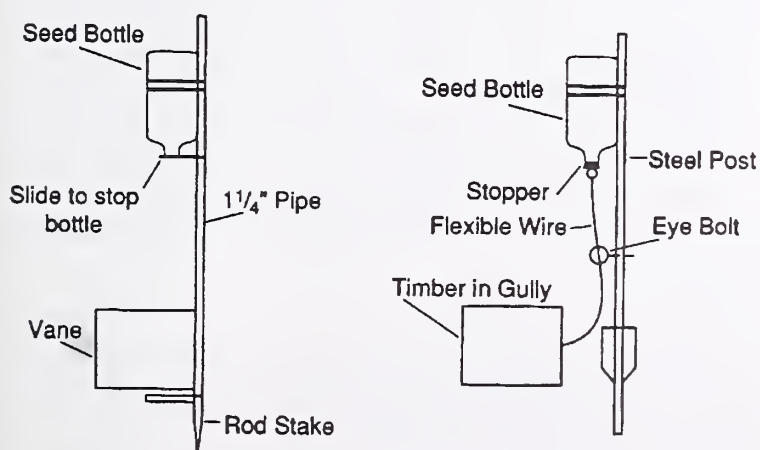

Figure 3—Two types of gully seeders tested at Jornada Experimental Range.

DISCUSSION

From these observations, seed of grass and shrub species are readily carried downstream by flood water. Flooding often provides favorable conditions for seed germination and establishment along waterways. In small gullies where the water flow is slowed and the seedlings become established, several things occur. The plants become a seed source for subsequent downstream seeding and further slowing and catching seed from upstream. These small gullies become filled with sediment, and the grass and shrub populations establish themselves along the gully, often restructuring these channels. As water flow slows, infiltration would improve. The increased water infiltration and fertility along the channels as compared to the slopes provides a special environment and would allow native species to reoccupy these areas.

Possible low-input management methods might include the establishment of grass and shrub communities in the upper slopes of selected gullies or streambeds. This could be enhanced by root plowing, damming, use of portable and temporary irrigation systems, or gully seeders where investment may be justified because of the potential productivity of sites. Once these communities have been established, they would become sources for downstream seeding. Downstream establishment could also be enhanced by downstream damming, and chemical or mechanical brush control along the potentially productive channels. With minimal input these methods could be initiated annually as resources are available, yet they would have long-term effects on downstream seeding and establishment of desirable plant communities.

REFERENCES

Buffington, L. C.; Herbel, C. H. 1965. Vegetation changes on a semidesert grassland range from 1858 to 1963. Ecological Monographs. 35: 139-164.

Cook, C. W. 1958. Sagebrush eradication and broadcast seeding. Bull. 404. Logan, UT: Utah Agricultural Experiment Station.

Herbel, C. H. 1973. Some developments related to seeding western rangelands. Range research and range problems. Spec. Publ. 3. Madison, WI: Crop Science Society of America: 75-80.

Herbel, C. H.; Abernathy, G. H.; Yarbrough, C.; Gardner, D. K. 1973. Rootplowing and seeding arid rangelands in the southwest. Journal of Range Management. 26: 193-197.

McKell, C. M.; Garcia-Moya, E. 1989. North American shrublands. In: McKell, C. M., ed. The biology and utilization of shrubs. San Diego, CA: Academic Press: 3-23.

McKell, C. M. 1989. Management practices for shrub-dominated lands to assure multiple-use benefits. In: McKell, C. M., ed. The biology and utilization of shrubs. San Diego, CA: Academic Press: 575-570.

Valentine, J. 1980. Range developments and improvements. 2d ed. Provo, UT: Brigham Young University Press. 545 p.

Section 4—Ecology and Management of Upland Shrubs

EFFECTS OF A SIMULATED PLUVIAL MAXIMUM CLIMATE ON SOIL-PLANT WATER RELATIONS AND POTENTIAL RECHARGE NEAR YUCCA MOUNTAIN, NEVADA

S. D. Smith
C. A. Herr
S. L. Hokett
G. F. Cochran

ABSTRACT

A pluvial maximum climate applied to experimental plots in the vicinity of the proposed Yucca Mountain high-level nuclear waste repository resulted in the alleviation of summer dormancy in all shrub species tested. Deep soil-moisture recharge (below 1.2 m) occurred within the first summer on bare plots but not until winter dormancy on vegetated plots. Deep soil-moisture recharge may occur in this arid region if pluvial climatic conditions return during the life of the repository.

INTRODUCTION

The U.S. Department of Energy (DOE) is in the process of conducting a wide range of site characterization studies at Yucca Mountain, NV, to determine if the arid Mojave Desert location is suitable as a high-level nuclear waste repository. An important mandate of the research program is a demonstration that the Yucca Mountain location is capable of isolating radionuclides from the environment for at least 10,000 years (Malone 1990). One area of potential concern is the role of surface precipitation in recharge to deeper groundwater zones, since groundwater may affect transport of radionuclides from the repository to the accessible environment. Although arid regions are considered to be ideal for waste isolation purposes, recent research suggests that such a premise has led to groundwater contamination by radionuclides (Nativ 1991).

Recharge of precipitation to groundwater apparently does not occur in the present arid Mojave Desert climate (Lane and others 1984). However, since the repository must remain intact for at least 10,000 years, both current and projected hydrogeologic conditions require extensive study. One possible climatic scenario is a return to the pluvial conditions that occurred 10,000 to 18,000 years ago; a time when the present internal drainage basins were filled to varying degrees with pluvial lakes, and the bajadas (alluvial fans) of the slopes were covered with vegetation that was considerably more mesic than what occurs there today (for example, pinyon-juniper woodlands instead of desert scrub; Spaulding 1983). Given such an environmental shift, the zero-recharge scenario that depicts the region today may not apply to pluvial conditions.

In 1987-88 a descriptive study of the plant-water relations and soil-moisture content of three representative geomorphic surfaces was conducted in the Yucca Mountain region (Smith and others 1989); the study confirmed that moisture recharge to deep soil layers does not occur under typical rainfall conditions. In this study, those observations were expanded on by creating plots in a desert wash to which a simulated pluvial maximum water budget was administered. A large wash was selected for the experimental plots based on the assumption that this type of landform is where groundwater recharge would be most likely to occur in a desert setting (Stephens and Knowlton 1986). The primary purpose was to determine if recharge may occur in the event pluvial conditions return to the region.

STUDY SITE AND DESIGN

The study was conducted about 160 km north of Las Vegas, NV, and 13 km north of the proposed Yucca Mountain exploratory shaft (36°55'N, 116°33'W, 1,300 m elevation). The dominant vegetation of the area was that typical of the northern Mojave/Transition Desert (Beatley 1980), with an assemblage of shrubs that included *Coleogyne ramosissima* (blackbrush), *Ephedra nevadensis* (Nevada Mormon tea), *Larrea tridentata* (creosotebush), and *Yucca brevifolia* (Joshua tree).

Experimental plots, each 25 m² in area, were established in early 1989 in a broad ephemeral wash. The plots were established in pairs along a 100-m section of the wash, and for each pair of plots, one plot was cleared (and maintained clear) of all aboveground vegetation so that water flux characteristics of bare and vegetated plots could be compared. Of the vegetated plots, two were monospecific *Coleogyne*, and two were of a mixed-shrub community consisting of *Coleogyne*, *Ephedra*, *Salazaria mexicana* (bladdersage),

and *Eriogonum fasciculatum* (yellow buckwheat), which allowed a comparison of the responses of a monospecific-shrub community with a mixed-shrub community. Regions of the wash with relatively high shrub cover were chosen to approximate the higher perennial plant cover that may be expected in a moister pluvial setting.

Paired plots were trenched to a depth of 1.5 m, and soil column side walls were double wrapped with thin and then heavy-duty plastic to prevent lateral water movement and root migration between the plots and the open desert wash environment, which served as a control (current Mojave Desert environment) for all measurements.

The pluvial climate model simulated in this experiment was determined by calculating the difference in consumptive use between modern conditions and the pluvial maximum that may have occurred in Beatty, NV, the closest weather station to the study site. Temperature and precipitation data of the pluvial maximum were based on Spaulding (1983). All plots were irrigated twice per month with the amount that would result in similar levels of effective precipitation as occurred during the pluvial maximum, minus the amount of precipitation actually falling on the site. The amounts applied each month accounted for not only the higher precipitation that occurred in pluvial times, but also the lower temperatures and higher relative humidities that occurred then, which would lower the evaporative power of the atmosphere relative to modern times. Thus, the irrigation amounts used to simulate a pluvial climate were greater than the actual precipitation that occurred during the pluvial maximum. Actual amounts of water applied to the plots on a monthly basis, plus precipitation the site received as measured with an onsite rain gauge, are given in table 1. As can be seen from the irrigation plus precipitation amounts, a three- to fourfold increase in seasonal precipitation occurred under the pluvial model.

Table 1—Irrigation regime followed to simulate a pluvial maximum climate as compared to monthly precipitation that actually occurred on site. Each 2-week irrigation amount was corrected by the previous 2-week incident rainfall. Irrigation was discontinued in 1990

Year	Month	Precipitation	Irrigation
		--------- Millimeters ---------	
1989	March	6	35
	April	0	16
	May	8	27
	June	5	26
	July	0	26
	August	38	34
	September	0	10
	October	0	11
	November	5	31
	December	0	34
1990	January	5	23
	February	3	40
	March	6	35
	April	1	0
	May	26	0
	June	3	0
	July	5	0

The variability between monthly amounts of rainfall in the pluvial model was also lower than occurs under the present arid Mojave Desert climate. Irrigation treatments were discontinued in March 1990.

SOIL MOISTURE AND PLANT-WATER RELATIONS

Time Domain Reflectometry (TDR) was utilized to evaluate *in situ* volumetric soil moisture content (Dalton and others 1984); TDR is particularly useful in measurements of wetting fronts in the vadose zone (Topp and others 1982). Horizontal, paired, stainless steel TDR probes were placed in a side wall of each plot at 0.15-m intervals from 0.15- to 1.20-m depths prior to backfilling. In addition, vertical, paired TDR probes were placed near the center of each plot at 0.15-, 0.3-, 0.6-, 0.9-, and 1.2-m depths. Readings were taken every 2 weeks throughout the 1989 growing season both before and after watering and were continued periodically in 1990.

Measurements of the water relations of shrubs in the experimental plots were taken twice monthly during 1989 and compared on each date with control plants located in the wash near the plots. Xylem water potentials were obtained at dawn and midday using a portable pressure chamber apparatus (Plant Moisture Stress Inc., Corvallis, OR) by removing three to five random shoots per species from each plot and from controls and immediately determining their water potential. Stomatal conductances of terminal leafy shoots were measured at several intervals during the day using a Lambda Instruments LI-1600 steady-state porometer (LI-COR, Lincoln, NE). For the two *Coleogyne* plots, four tagged shoots were monitored per plot; two shoots each of *Ephedra*, *Eriogonum*, and *Salazaria* were monitored on the mixed plots. An equal number of measurements were made for each species on randomly selected control plants that were permanently tagged in the wash area between the experimental plots.

RESULTS AND DISCUSSION

Seasonal patterns of predawn (maximum daily) water potential for irrigated (pluvial) and control plants during the 1989 growing season are shown in table 2. The data represent means of all measurements, and so the means include water potentials of *Coleogyne*, *Ephedra*, *Eriogonum*, and *Salazaria*. Predawn water potentials were uniformly low in control plants throughout 1989, which was a very dry year. Plants briefly rose above –6.0 MPa in May, but remained at below –7.0 MPa throughout most of the year, finally rising to about –5.0 MPa in response to late-summer rains. In contrast, plants on the experimental plots quickly elevated to about –2.0 MPa in the spring and early summer, but then fell back to about –4.0 MPa in late summer even though irrigation continued. Plants then rehydrated to about –2.0 MPa in September.

Similar trends in maximum (early to mid-morning) stomatal conductance were observed in the two populations (table 2). Control plants stayed dormant (no measurable gas exchange) for virtually the entire growing season; plants on the irrigated plots exhibited very high stomatal conductances (up to 0.8 mol m^{-2} s^{-1}) in midsummer. Stomatal

Month	Water potential[1]		Stomatal conductance	
	Control	Irrigated	Control	Irrigated
	- - - - - - MPa - - - - - -		- - - - - mol $m^{-2} s^{-1}$ - - - - -	
March	−7.0	−7.0	0	0
April	−6.2	−4.1	0	.06
May	−6.6	−2.1	.04	.16
June	−7.0	−2.0	.03	.39
July	−7.0	−4.1	0	.75
August	−6.5	−3.9	.03	.50
September	−5.0	−2.4	.05	.34
October	−5.5	−2.5	.02	.30
November	−6.8	−2.2	.02	.26

[1]Values listed as −7.0 indicate that the actual water potential was less than or equal to −7.0 MPa.

conductance appeared to be reduced in the irrigated plants by cool temperatures in the spring and then by declining water potential in the late summer. Part of the cause of declining water potential in late summer was undoubtedly rapid transpirational water loss of the vegetation in the midsummer period.

Seasonal patterns in volumetric soil-moisture content in the upper 0.6 m of the soil profile, the region of greatest root density, are given in table 3 for the three types of experimental plots: bare, *Coleogyne*, and mixed-shrub. All moisture contents represent readings just prior to each 2-week irrigation treatment. Soil moisture content in the control (open desert) areas was uniformly low throughout 1989-90, averaging only 1-3 percent. After commencing irrigation in March 1989, soil moisture in all the plots rose from 2-4 percent to 5-6 percent within 2 months, but then continued to rise only in the bare plots, where it reached a plateau of about 8-10 percent for the duration of the experiment. Vegetated plots remained at only about 4 percent soil moisture throughout the growing season, presumably because of rapid soil moisture uptake by the plant root systems. Then, when the vegetation became winter dormant in November, soil moisture rapidly increased to similar values as in the bare plots. In March 1990, the vegetated plots again began losing water via plant transpiration, and so soil moisture in the upper profile declined to about 5 percent thereafter.

The vertical distribution of soil moisture at three critical times during the experiment (March 1989, January 1990, and July 1990) is shown in table 4 for both bare and vegetated plots. At the start of the experiment, soil moisture content was between 2 and 4 percent throughout the soil profile. By January 1990 the soils of the bare plots were above 8 percent soil moisture down to 1.05 m. The vegetated plots exhibited peak soil moisture of over 10 percent at the 0.6 m depth, but showed reduced soil moisture both above and below that depth. The soil moisture profile was also measured in July 1990, 4 months after the last irrigation occurred in March. The bare plots showed essentially no change relative to January soil moisture contents. However, the vegetated plots had lost considerable amounts of

moisture and exhibited 2-6 percent soil moisture through most of the profile. The consistent peak in soil moisture at the 0.45- to 0.75-m depths in the vegetated plots suggests that a majority of water absorption occurred on these plots in the upper 0.3 m of the profile. Since the bare plots did not exhibit a similar peak, a midprofile, finer textured layer effect can presumably be ruled out. However, the deepest layers had the highest water content in July, indicating a lack of extraction by the vegetation at that depth since the termination of irrigation on the plots.

A hydrologic water budget was computed for each plot by combining and integrating all TDR moisture readings (both vertical and horizontal probes) to determine total moisture storage just prior to each 2-week irrigation. Since rates of water application were known, and the plots were essentially closed soil systems (no lateral transport), changes in whole-profile moisture storage could be used to calculate rates of water loss from the plots. These calculated rates of water loss, plus amounts of applied water, are summarized in table 5 for each season of the study. Rates of applied water exceeded plot water loss in three of the six seasonal periods studied, and approximately equaled plot water loss in two others. Only in spring 1990 did water loss from the vegetated plots exceed water application. This was probably a lag effect in which the shrubs leafed out at the start of the spring and were then exposed to a uniformly wet soil profile throughout the rooting zone, optimum conditions for rapid soil water extraction. However, the fact that applied water exceeded plot water loss for over half of the experiment indicates the potential for deep percolation of soil moisture below the rooting zone to occur on a regular basis. Additionally, the fact that the bare plots consistently lost less water than was applied indicates that, in a pluvial climatic setting, zones of bare soil (such as active wash channels) may be primary locations for deep soil recharge to occur.

Year	Month	Soil water content		
		Bare	*Coleogyne*	Mixed-shrub
		- - - - - - - - - - - Percent - - - - - - - - - - -		
1989	March	4.2	2.8	2.8
	April	4.9	4.3	3.6
	May	6.3	5.0	4.2
	June	7.4	4.2	4.4
	July	7.7	4.1	4.2
	August	8.7	4.5	4.1
	September	7.9	4.1	4.1
	October	7.7	4.1	3.3
	November	7.9	4.2	3.7
	December	9.2	6.8	6.6
1990	January	9.4	7.9	9.6
	February	9.6	8.7	10.3
	March	9.8	8.5	10.1
	April	10.1	7.0	7.4
	May	9.2	5.2	5.9
	June	8.1	4.1	5.0

Table 4—Vertical profile of volumetric soil water content for bare and vegetated plots at three times during the experiment: March 1989 (start of experiment); January 1990 (middle of winter dormancy period); and July 1990 (end of experiment)

| | Volumetric soil water content | | | | | |
| | Bare plots | | | Vegetated plots | | |
Depth	Mar. 1989	Jan. 1990	July 1990	Mar. 1989	Jan. 1990	July 1990
Meters	- -Percent- -					
0.15	3.0	9.3	6.4	1.3	6.1	1.5
.30	2.8	9.6	8.2	4.0	7.5	2.7
.45	2.7	8.9	8.2	4.8	9.3	5.4
.60	1.4	8.0	7.1	4.5	10.3	4.5
.75	2.6	8.6	8.2	2.9	8.2	3.3
.90	3.2	8.3	8.3	2.7	4.5	3.0
1.05	2.4	7.5	7.1	2.7	2.7	3.1
1.20	2.6	4.1	5.2	4.0	3.9	5.2

Table 5—Amounts of applied water and calculated water loss from bare and vegetated plots integrated over whole seasons during the length of the experiment

| | | Water applied or lost | | |
Year	Season	Applied water	Bare plot loss	Vegetated plot loss
		- - - - - - - - - - - - - - - - - *Millimeters* - - - - - - - - - - - - - - - - -		
1989	Spring	59	29	42
	Summer	132	92	113
	Fall	46	26	43
1990	Winter	109	89	33
	Spring	84	83	155
	Summer	8	31	26

Table 6—Wetting front advancement through the soil profile for bare and vegetated plots. Reported values represent the depths at which a majority of the plots (at least three) had a wetting front, rather than a numerical mean of the four plots in each category. Irrigation treatments commenced in March 1989 and terminated in March 1990

| | | Wetting front depth | |
Year	Month	Bare plots	Vegetated plots
		- - - - - - - - - - -*Meters* - - - - - - - - - -	
1989	April	0.45	0.15
	May	.60	.30
	June	.75	.60
	July	.90	.60
	August	.90	.60
	September	1.05	.60
	October	1.05	.60
	November	1.05	.60
	December	[1]1.20	.75
1990	January	1.20	1.05
	February	1.20	1.05
	March	1.20	[1]1.20

[1]Below depth of deepest horizontal probes, located at 1.2 m.

Using the horizontally placed TDR probes at 0.15-m intervals, soil wetting fronts could be followed during the experiment (table 6). Wetting front advancement consistently increased in depth throughout the experiment in the bare plots, and descended below the deepest probe (1.2 m) on several of the plots by December 1989. In contrast, the wetting front remained above 0.6 m in the vegetated plots during the season of active transpiration, but then fell below 1.2 m by March 1990 during the period when the vegetation was in winter dormancy. Thus, applied moisture penetrated below the deepest probes, and the probable rooting depths of these desert shrubs, in both the bare and vegetated plots during the 12-month period that the experiment lasted.

CONCLUSIONS

This preliminary study indicates that even though a pluvial climate may remove summer dormancy in Mojave Desert scrub vegetation and that the vegetation may use all available soil moisture during the growing season, deep recharge of soil moisture below the rooting zone would be expected to occur during the 4- to 5-month period of winter dormancy. Although it was obviously not possible to simulate a gradual return to pluvial conditions (over a 5,000- to 10,000-year period) and the concomitant changes that would be expected to occur in vegetation cover and species composition, the results of this study clearly indicate that recharge would be expected to occur in the winter months, not during the growing season when plant transpiration would probably keep pace with precipitation inputs. If pluvial conditions were indeed cooler and moister than today, then winter dormancy of the vegetation may have lasted considerably longer in pluvial times, thus increasing the length of time that a "recharge window" would exist. In fact, recent hydrologic studies in the vicinity of Yucca Mountain have determined that groundwater of about 10,000 years old or younger occurs beneath a major wash system (R. Jacobson, pers. comm.).

This study indicates that if the Mojave Desert were to return to pluvial climatic conditions in the next 10,000 years, recharge of soil moisture below the rooting zone may occur

in the area, either in vegetated zones during winter dormancy or in open areas with no vegetation, such as coarse-textured active channels in large wash systems. Stable isotopic analysis of layered carbonates and silica encrusted in fault fractures indicates that the regional water table beneath Yucca Mountain has probably remained below the proposed repository for at least several hundred thousand years (Quade and Cerling 1990). However, the results of this study indicate that there is a reasonable probability that soil moisture recharge may occur in the Yucca Mountain region within the life of a potential repository if the region were to return to pluvial climatic conditions. Clearly, more detailed studies need to be conducted to address this possibility.

REFERENCES

Beatley, J. C. 1980. Fluctuations and stability in climax shrub and woodland vegetation of the Mojave, Great Basin, and transition deserts of southern Nevada. Israel Journal of Botany. 28: 149-168.

Dalton, F. N.; Herkelrath, W. N.; Rawlins, D. S.; Rhoads, J. D. 1984. Time-domain reflectometry: simultaneous measurement of soil water content and electrical conductivity with a single probe. Science. 224: 989-990.

Malone, C. R. 1990. Implications of environmental program planning for siting a nuclear waste repository at Yucca Mountain, Nevada, USA. Environmental Management. 14: 25-32.

Nativ, R. 1991. Radioactive waste isolation in arid zones. Journal of Arid Environments. 20: 129-140.

Quade, J.; Cerling, T. E. 1990. Stable isotopic evidence for a pedogenic origin of carbonates in Trench 14 near Yucca Mountain, Nevada. Science. 250: 1549-1552.

Smith, S. D.; Leary, K.; Herr, C.; Hokett, S. 1990. Water relations and transpiration of native vegetation in the vicinity of Yucca Mountain, Nevada. In: Proceedings—symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 250-255.

Spaulding, W. G. 1983. Vegetation and climates of the last 45,000 years in the vicinity of the Nevada Test Site. Open File Report 83-535. Carson City, NV: U.S. Geological Survey. 83 p.

Stephens, D. B.; Knowlton, R., Jr. 1986. Soil water movement and recharge through sand at a semiarid site in New Mexico. Water Resources Research. 22: 881-889.

Topp, G. C.; Davis, J. L.; Annan, A. P. 1982. Electromagnetic determination of soil water content using TDR: I. Applications to wetting fronts and steep gradients. Soil Science Society of America Journal. 46: 672-678.

POTENTIAL IMPACTS OF WESTERN JUNIPER ON THE HYDROLOGIC CYCLE

Lee E. Eddleman
Patricia M. Miller

ABSTRACT

Precipitation throughfall, stem flow, and interception and foliage transpiration of western juniper (Juniper occidentalis Hook. ssp. occidentalis) *were examined in central Oregon. Stem flow ranged from 1.0 percent to 3.2 percent, throughfall from 33.0 percent to 52.3 percent, and interception from 44.4 percent to 65.9 percent of incoming precipitation depending on tree size and type of precipitation. Transpiration, which may occur yearlong, reached 3.03 L/kg of foliage in summer months when soil moisture was high. Winter soil moisture recharge may be reduced over 50 percent by dense western juniper woodlands.*

INTRODUCTION

Western juniper (*Juniperus occidentalis* Hook. ssp. *occidentalis*) occupies the zone between the ponderosa pine forest and the lower elevation sagebrush grassland in eastern Oregon, southwestern Idaho, northwestern Nevada, and northeastern California. Aerial extent of the woodland dominated by western juniper has increased markedly over the last 100 years (Adams 1975; Burkhardt and Tisdale 1969; Eddleman 1987; Young and Evans 1981). Ancient western juniper woodlands can be found; these are generally located either on rocky ridges or on areas where soils contain considerable pumice sand. Woodlands of more recent origin are found primarily on areas previously occupied by big and low sagebrush-bunchgrass communities.

Aggressive spread of western juniper into the mountain big sagebrush type has resulted in very dense stands, numbering from a few hundred to several hundred individual trees per hectare (Eddleman 1987). Considerable concern has developed over the change in ecosystem structure and processes resulting from shifts in these plant communities. Initial concern focused on loss of forage and ground cover for protection against soil erosion; however, of equal concern is the impact on the yearly water cycle within the entire watershed.

Land managers in the central Oregon area have reported loss of springs where recent western juniper woodlands become the aspect dominant and at the same time noted that, for some drainages, springs returned or flow increased when some level of control was applied.

Potential indirect impacts of juniper woodlands on the hydrologic cycle can be expected to include processes of surface water runoff and evaporation from the soil surface. Both processes are likely elevated due to a reduced ground cover in the interstices between tree canopies (Vaitkus and Eddleman 1987). Runoff as indicated by erosional processes was investigated by Buckhouse and Mattison (1980) and found to be strongly accentuated on juniper-dominated lands. They concluded that sediment yield was two to three times higher on juniper-dominated sites than sites dominated by mountain big sagebrush-bunchgrass, an indication of the potential for accelerated water runoff with vegetation type change to western juniper.

Potential direct impacts of western juniper on the yearly hydrologic cycle include processes of precipitation interception by canopy and litter and transpiration, processes dominated by juniper rather than by herbaceous perennials and sagebrush.

Both direct and indirect impacts of the vegetation type conversion from sagebrush-bunchgrass to one of western juniper dominance would be expected to alter timing and amounts of streamflow and therefore recovery rates of deteriorated riparian areas in semiarid environments. The direct effects of interception and transpiration by western juniper on hydrologic cycles in these systems are somewhat less understood than the indirect effects and are therefore the focus of this paper.

STUDY AREA AND METHODS

The study area is located in a central Oregon area stretching from Sisters to Prineville and Post. Elevation within the main part of the woodland under study ranges from 1,000 to 1,500 m. Mean annual precipitation in this area varies from 230 mm to 400 mm, with highest inputs in midwinter and again in May and June. Little precipitation falls from July through mid-September. Plant growth is initiated about March 1, accelerates in April and May, and terminates about mid-July.

Soil texture varies from heavy to medium, frequently with inclusions of volcanic pumice and stone. Soil depth varies from 30 to 100 cm, although soils commonly are about 50 cm deep (Pomerening and others 1983).

Interception

Precipitation (*P*) throughfall (*T*), and stem flow (*SF*) for western juniper were measured in a western juniper woodland located at an elevation of 1,300 m between Prineville and Post, OR. Annual precipitation averages approximately 340 mm. Three canopy diameter size classes (2, 4, and 6 m) were selected for measurement. Measurements were made

on four trees within each size class. Trees were selected from those of normal canopy shape and canopy density. Trees in the 2-, 4-, and 6-m diameter size classes averaged 4.0, 6.8, and 10.4 m tall, respectively, while bole basal diameters averaged 14.6, 35.0, and 54.0 cm, respectively.

Canopy throughfall was measured with a wedge-shaped proportionate area catchment trough, representing 2 percent of the canopy area, extending from the bole of the tree to the canopy margin, and which then drained into a container. Stem flow was collected from a gutter attached to the basal bole of the tree, which drained into a large container. Three U.S. Forest Service-type rain gauges were located nearby in large openings to measure precipitation input. Interception (I) by the tree canopy was calculated from:

$$I = P - (T + SF)$$

Measurements were taken for 22 (18 rain and four snow) storm events occurring from mid-June 1985 through mid-June 1986. Contents of containers were determined within a day or two following the storm with the exception of a few snow storms where measurement was delayed until the snow disappeared from the canopy. Mineral oil was used in the warm months to prevent evaporation, and antifreeze was used in the cold months to prevent freezing in the containers.

Transpiration

Measurements were conducted at an elevation of 1,050 m in an area between Sisters and Redmond, OR. Annual precipitation at Redmond, about 13 km to the east of the study site, is 217 mm. Diurnal measurements of physiological processes were made on adult western junipers, average of 4.5 m in height, from July 1987 through October 1988. Twelve sets of measurements were made during this period of time. Each set (a set equals a 1- to 2-day period) consisted of repeated measures on each tree (nine to 24 times) at spaced intervals from predawn to postdusk. Numbers of trees measured and dates of measurement in 1987 were: five on July 29, two on August 10, two on November 21. In 1988 they were: one on January 2, and four each time on April 2, April 16, May 8-9, June 11-12, July 6-7, August 2-3, September 4-5,

and September 30-October 1. Branchlets selected for physiological measurements were taken on the south side of the tree at 1.5 m above the ground surface.

Carbon dioxide assimilation and relative humidity were measured using an Analytical Development Corp. LCA-2 portable infrared gas analyzer system. Leaf conductance, transpiration, and intercellular carbon dioxide concentrations were calculated. Leaf and air temperatures were measured with fine gauge copper/constantine thermocouples and a Campbell Scientific CR 10 data logger. Daily totals of transpiration were calculated by integration under measured diurnal curves. Leaf biomass was calculated from ovendry weight of branchlets. Daily whole plant transpiration was calculated using measured diurnal curves of transpiration and whole tree leaf biomass regression equations developed by Miller and others (1987). The equation used is $Y = -5.381 + 0.352(X)$ where Y equals the leaf biomass (kg) and X equals the basal circumference (cm) of the bole at the litter surface.

INTERCEPTION RESULTS

A total of 18 measurable rainfall events, totaling 116 mm, occurred during the study period. Of these, 14 were less than 10 mm. An additional four snow storm events were measured, one a combination of two storms, the first of which did not melt prior to the second, so they were combined. Total measured precipitation input as snow was 212 mm. Other snow storms occurred; however, problems with ice and other destructive forces rendered the data unusable. Snows were heavy, wet events with little wind, resulting in snow remaining on the canopy until it sublimated or melted rather than falling through the canopy.

Table 1 provides information as to the fate of precipitation from 22 measurable storm events that produced a total of 328 mm of precipitation. Very little stem flow occurred, ranging from about 1 percent for large trees to a little over 3 percent for small trees. These differences are likely the result of exposed canopy surface area, which averaged 11.4, 18.4, and 29.8 m², respectively, for the 2-, 4-, and 6-m canopy diameter size classes. Throughfall percentage appears to decrease as canopy size increases, with rainfall producing higher amounts of throughfall than snowfall in the larger

Table 1—Partitioning of precipitation by western juniper tree canopies

Number	Canopy diameter class	Stem flow	Throughfall	Canopy interception
	Meters	----------- *Percent* -----------		
Total (22)	2	3.2	52.3	44.7
	4	2.3	39.6	58.1
	6	1.0	35.9	63.1
Rain (18)	2	3.2	52.3	44.4
	4	2.2	50.4	47.4
	6	.8	41.2	58.0
Snow (4)	2	2.9	52.3	44.8
	4	2.3	33.5	64.2
	6	1.1	33.0	65.9

size classes. Much of the throughfall is expected to pass through openings in the canopy; however, with large storms drip from branch and foliage surfaces is common.

Canopy interception, which was calculated as the difference between total input and that which reaches the ground surface, appears to increase with canopy size. Intercepted amounts were estimated in excess of 60 percent for the larger canopy size class. Intercepted snowfall was high, perhaps due to the nature of the particular snow storms included in the measurement.

Interception increased in a linear fashion as the size of the rainfall event increased (fig. 1); however, few data points are available for larger storm events. A leveling off is expected when the canopy saturation point is reached.

TRANSPIRATION RESULTS

Water use by western juniper is potentially high (table 2). High transpiration rates are dependent on high amounts of water being available in the soil profile. When soil moisture was low, as it was in 1988 as compared to 1987, transpired water was reduced. Plant available water may be essentially absent from the surface soils; however, western juniper continues to remain physiologically active, presumably accessing deep water by its taproot.

Two examples of measured stands of western juniper in central Oregon are given in table 3. Most stands in central Oregon that are approaching maturity will have characteristics that fall somewhere in between these stands. Stands of recent origin, such as these, frequently achieve very high densities, foliage biomass, and canopy cover for semiarid ecosystems. The potential impact of each of these two stands due to moisture interception and transpiration is estimated in table 4. Amounts of precipitation reaching the ground surface during the soil-moisture recharge period are potentially much reduced by dense woodlands. Understory herbaceous vegetation begins active growth in April; however, major leaf expansion occurs in May and early June. By this time available soil moisture may be much reduced due to

Table 2—Calculated daily total water transpired for western juniper

Year	Month	Transpiration Per kg foliage[1]	Whole tree[2]
		L/day	L/gal/day
1987	July	3.03	132/35
	Aug.	3.03	132/35
	Nov.	.34	15/4
1988	Jan.	.11	5/1
	April	1.90	83/22
	May	2.07	90/24
	June	2.41	105/28
	July	1.74	76/20
	Aug.	2.24	98/26
	Sept.	1.51	66/17
	Oct.	1.06	46/12

[1]From calculations of Miller 1990.
[2]Tree with a 44.4-cm (17.5-inch) diameter bole at litter surface. Foliage biomass calculated using equations from Miller and others (1987).

Table 3—Characteristics of two western juniper stands from central Oregon

Stands	Basal diameter	Number/ha[1]	Foliage biomass	Canopy cover
	[2]cm		[3]kg/ha	Percent
Stand 1	>30	40		
	15-29	65		
	2-14	220		
	<2	115		
Total		440	2,865	22
Stand 2	>30	65		
	15-29	90		
	2-14	265		
	<2	825		
Total		1,245	4,920	39

[1]x 0.405 = number/acre.
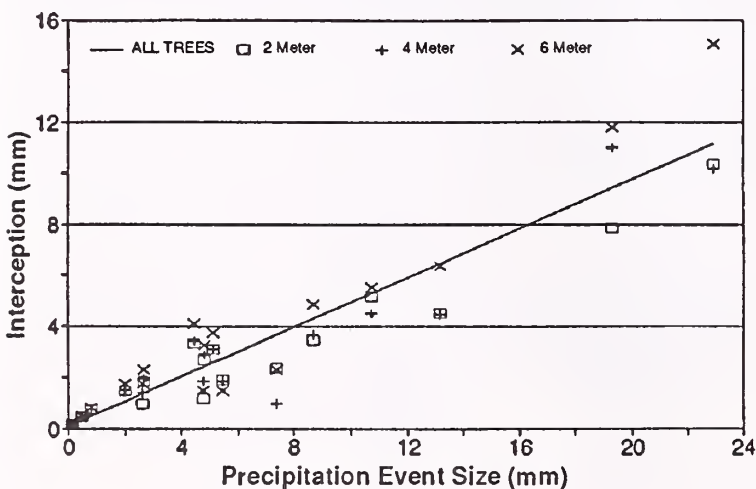[2]÷ 2.45 = inches.
[3]x 0.893 = lb/acre.

Figure 1—Interception of precipitation by western juniper canopy relative to precipitation event size. Line is regression of all tree sizes. Symbols are data points, each a mean of four trees in each size class. (All trees $Y = 0.0812 + 0.4848X$, $r^2 = 0.89$.)

juniper interception and transpiration that has been continuously in progress.

In the absence of western juniper, moisture penetration in the soil profile could reach 70-80 cm by the end of April. This amount would be reduced by evaporation from the soil and sagebrush-grass interception and transpiration of moisture.

Moisture penetration into the profile could reach 50-55 cm for stand 1 by the end of June; however, evaporation from the soil surface and understory plant transpiration are active processes during May and June; therefore, moisture penetration will be reduced. For stand 2, moisture penetration could reach 35-40 cm by the end of March. In this stand average soil moisture content can be expected to decline to a point in July when it is no longer available to plants for physiological processes.

In general the understory plant growth fits the scenario of table 4 as most of the plants in stand 1 become completely senescent by mid-July and in stand 2 by late June.

Table 4—Precipitation inputs and the potential effects of western juniper on yearly soil moisture accumulation

Month	Cumulative precipitation[3]	Soil moisture accumulation cumulative precipitation – $(T^1 + I^2)$	
		Stand 1	Stand 2
		- *mm* -	
Oct.	[3]20	9	0
Nov.	56	38	24
Dec.	92	69	51
Jan.	125	98	76
Feb.	146	116	92
Mar.	165	124	92
Apr.	181	122	77
May	208	128	67
June	234	130	52
July	240	108	11
Aug.	254	93	—
Sept.	265	90	—

[1]Transpiration (T) calculated from tables 2 and 3.
[2]Interception (I) calculated from cover values (table 3) and interception of 47.4 percent (table 1). Stand I = precipitation (mm) x ((percent cover x percent I)/10,000).
[3]Thirty-year average for precipitation, Prineville, OR.

DISCUSSION

Estimates of the total impact by western juniper in central Oregon on the water cycle due to interception loss and transpiration use are considered to be conservative. Values used for interception (table 4) were for rainfall only and for intermediate-sized trees. Snowfall interception losses are likely higher; however, snowfall in this zone is normally a lesser percentage of the total moisture than is rainfall. Calculated interception values are somewhat higher than those reported by Young and others (1984). Trees used in this study did have very dense canopies; therefore, greater interception may have resulted. Storm intensities may also be a contributing factor.

This zone is on the average warmer in the winter than were the months for which transpiration measurements were made so that total transpiration could be potentially higher. Models based on light, temperature, vapor pressure deficit, and available soil moisture are currently being developed (Miller and others 1987). Hourly values of these factors, which are being used to refine the model, are currently being monitored within the system. Transpiration values calculated in this study are comparable with those reported by Miller and others (1987) for eastern Oregon.

The impact of western juniper on the upland hydrologic cycle is significant. Whether or not it reduces the amount of subsurface water flow to riparian areas is questionable. There are perhaps three ways by which the woodland could reduce subsurface water flows.

The first possibility has to do with the shallow soil profile. Since soils over much of the western juniper zone in central Oregon average approximately 50 cm deep and overlay cobble or fractured rock, there would appear to be little possibility for percolation below the soil profile with juniper present. Without juniper, average precipitation years might contribute some moisture to deep percolation and subsurface flows. In years with above-average precipitation, perhaps significant contributions to subsurface flow could occur.

Seasonal distribution of precipitation may be an important factor to consider. Approximately two-thirds of the yearly moisture comes in the cool period of October through April, a time period when grasses, forbs, and most shrubs transpire little or no moisture. However, a mature western juniper woodland may transpire 20 to 30 percent of the moisture received during this period of time and intercept an additional 10 to 20 percent with its canopy. As a result, winter soil-moisture recharge should be less than in a sagebrush-bunchgrass community where interception is less a factor and transpiration is minimal.

Second, after the soil profile has been dried, western juniper can continue transpiration by pumping water accessed by its deep taproot (Kramer 1990; Miller 1990). Moisture stored below the soil profile in above-average precipitation years is likely to be depleted during the summer and fall months and may not have the opportunity to accumulate from year to year.

Third, much of the western juniper zone lies below higher elevation upland portions of the watershed that receive considerably more moisture; therefore, it may be the last ecosystem through which runoff and subsurface water pass before entering the riparian zone. Subsurface flow generated above the juniper zone may very well be accessed by the deep roots of western juniper, and this flow could conceivably be reduced or perhaps eliminated across broad upland landscapes.

CONCLUSIONS

In general, this study indicates that western juniper potentially plays a major role in the hydrologic cycle of central Oregon. As the canopy cover of western juniper increases, interception loss of precipitation can be expected to increase. Precipitation interception by large mature trees was found to slightly exceed 0.6 percent for each 1 percent canopy cover.

Use of soil moisture by western juniper in the transpiration process is potentially a yearlong phenomena in situations where winter climates are sufficiently warm. Both cool temperatures and low soil moisture reduce transpiration, while conditions of high soil moisture and high temperature result in maximal transpiration. July and August transpiration may reach 1.5 mm of soil moisture per day from a mature, dense (39 percent canopy cover) woodland when soil moisture is high. Transpiration may continue after soil moisture has been depleted, apparently through moisture accessed by deep taproots.

Moisture either intercepted or transpired by western juniper woodlands during the soil moisture recharge period could potentially reduce subsurface flow to riparian areas. However, Schmidt (1987) reviewed the literature and concluded that there is little reason to expect large responses in streamflow to control of pinyon-juniper woodlands. This may well apply to western juniper woodlands. Ultimately, the impacts of western juniper woodlands on riparian systems will have to be addressed at the watershed level and include all aspects of the hydrologic and nutrient cycle as well as biodiversity.

REFERENCES

Adams, A. W. 1975. A brief history of juniper and shrub populations in southern Oregon. Wildl. Res. Rep. 6. Corvallis, OR: Oregon Wildlife Commission, Research Division. 33 p.

Buckhouse, J. C.; Mattison, J. L. 1980. Potential soil erosion of selected habitat types in the high desert region of central Oregon. Journal of Range Management. 33: 282-285.

Burkhardt, J. W.; Tisdale, E. W. 1969. Nature and successional status of western juniper vegetation in Idaho. Journal of Range Management. 22: 264-270.

Eddleman, L. E. 1987. Establishment of western juniper in central Oregon. In: Everett, R. L., compiler. Proceedings—pinyon-juniper conference; 1986 January 13-16; Reno, NV.

Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 255-259.

Kramer, S. 1990. Development and morphology of juvenile western juniper (*Juniperus occidentalis* Hook.). Corvallis, OR: Oregon State University. 80 p. Thesis.

Miller, R. F.; Angell, R. F.; Eddleman, L. E. 1987. Water use by western juniper. In: Everett, R. L., compiler. Proceedings—pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 418-422.

Miller, P. M. 1990. Physiological ecology of western juniper (*Juniperus occidentalis* Hook. ssp. *occidentalis*). Corvallis, OR: Oregon State University. 275 p. Thesis.

Pomerening, J. A.; Thomas, L.; Thomas, B. 1983. Interim soil survey report of the Brothers area, Prineville, Oregon District. U.S. Department of the Interior, Bureau of Land Management. 372 p.

Schmidt, L. J. 1987. Present and future themes in pinyon-juniper hydrology. In: Everett, R. L., compiler. Proceedings—pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 474-479.

Vaitkus, M. R.; Eddleman, L. E. 1987. Composition and productivity of a western juniper understory and its response to canopy removal. In: Everett, R. L., compiler. Proceedings—pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 456-460.

Young, J. A.; Evans, R. A.; Easi, D. A. 1984. Stem flow on western juniper (*Juniperus occidentalis*) trees. Weed Science. 32: 320-327.

Young, J. A.; Evans, R. A. 1991. Demographics and fire history of western juniper stands. Journal of Range Management. 34: 501-506.

INFLUENCE OF SAGEBRUSH ON THE SOIL MICROCLIMATE

J. R. Wight
F. B. Pierson
C. L. Hanson
G. N. Flerchinger

ABSTRACT

Much of the sagebrush-grass rangeland in the Western United States is being converted to annual grassland by the invasion of annual grasses such as cheatgrass (Bromus tectorum). Cheatgrass reduces the biodiversity of the ecosystem and increases the frequency of wildfires. Effective management of this ecosystem requires the establishment of desirable perennial plant species. To accomplish this management goal, a better understanding of the influence of sagebrush on the near-surface soil microclimate is needed. This paper reports results of a study conducted in southwestern Idaho on the USDA, Agricultural Research Service, Reynolds Creek Experimental Watershed. Soil temperature and water potential were measured hourly at 1-, 5-, and 10-cm depths at 30-cm intervals along a 12.3-m transect through a sagebrush-grass plant community. Other variables measured at each sampling point included radiation at ground level, surface temperature, litter depth, and canopy cover. Maximum soil temperatures at the 1-cm depth differed by as much as 30 °C between interspace and shrub-covered areas. Shrub cover prolonged the periods of soil-water conditions favorable for seedling establishment. Solar radiation was reduced 50 percent or more by the sagebrush canopy. Reduced radiation and increased litter accumulation under sagebrush canopies significantly moderated the extremes in the soil microclimate.

INTRODUCTION

The sagebrush-grass ecosystem includes about 52.6 million ha in the Western United States (USDA FS 1980). This land is a major resource for livestock production, wildlife habitat, and onsite and downstream water supplies. Productivity of the sagebrush-grass ecosystem has been reduced in the past by livestock grazing (USDA SEA AR 1980) and is now threatened by the invasion of cheatgrass (*Bromus tectorum*). Cheatgrass is an introduced annual grass, which can form nearly pure stands and has resulted in an increase in wildfire frequency with subsequent reductions in biodiversity and resource values (Pellant 1990).

Effective management of these plant communities, to maintain or improve their productivity and biodiversity, will require increased knowledge concerning soil-plant-climate interactions, especially in the near-surface soil microenvironment in which seeds germinate and seedlings establish. This kind of information will help us better understand how cheatgrass invades a plant community and improve our ability to successfully seed more desirable native and introduced plant species into areas dominated by cheatgrass.

Much has been written concerning soils associated with sagebrush-grass plant communities and the modifying influence sagebrush plants have on soil infiltration, erosion, and related soil properties (Blackburn 1975; Blackburn and others 1990; Eckert and others 1986; Hugie and Passey 1964; Stuart and others 1971; Wood and others 1978). The modifying influence of sagebrush on the near-surface soil microclimate has been recognized (Pierson and Wight 1991), but little quantitative information is available. The purpose of this paper is to present such information and relate it to the ecology of plant establishment and growth within sagebrush-grass plant communities.

STUDY SITE

The study was conducted at the Quonset site on the Reynolds Creek Experimental Watershed in southwestern Idaho, about 80 km southwest of Boise. The site is at an elevation of 1,193 m with a mean annual precipitation of 276 mm, of which about 30 percent occurs as snow. The soil is a member of the Larimer series within the fine, loamy, mixed mesic family of Xerallic Haplargids. Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) is the dominant shrub and Sandberg bluegrass (*Poa sandbergii*) accounts for most of the understory vegetation.

METHODS AND PROCEDURES

Soil temperature and water potential measurements were recorded at 1-, 5-, and 10-cm depths at 30-cm intervals along a 12.3-m transect through the sagebrush-grass plant community. Additional measurements were taken at 20-, 30-, 50-, and 100-cm depths at a few locations along the transect. Microclimatic measurements at all soil depths were recorded hourly from day 320, 1988, to day 319, 1989, using thermocouple and gypsum block sensors connected to data recorders. Surface temperatures at

the 30-cm intervals along the 12.3-m transect were measured weekly at solar noon using a hand-held infrared thermometer. In addition to scheduled soil temperature and water measurements, one-time measurements of ground-level short-wave radiation, litter depth, and canopy cover along the transect were made in June 1989. Sagebrush and grass canopy cover was measured using a line-intercept method.

Accumulated heat units were calculated as growing degree days at the 1-cm depth using hourly soil temperature data for the 1989 growing season. The SHAW model (Flerchinger and Saxton 1989a,b) was used to simulate 1-cm soil temperatures at the study site using a stochastically generated 50-year climate record. The climate record was generated using the climate generator in the WEPP (Water Erosion Prediction Project) model (Nicks and Lane 1989).

RESULTS AND DISCUSSION

Sagebrush and grass canopy cover was about 30 and 8 percent, respectively, on the site. The distribution of sagebrush canopy and its effect on litter depth along the sampling transect is shown in figure 1. Litter accumulations under the sagebrush plants varied from 1 to 5 cm in depth and were comprised of litter, moss, and lichens. Smaller amounts of litter accumulated in interspaces between sagebrush plants and corresponded with the location of small clumps of Sandberg bluegrass. Very little litter accumulated in areas with no vegetation.

The sagebrush canopy had a dramatic effect on the amount of radiant energy that reached the surface of the soil or understory vegetation (fig. 2). This shade effect significantly influenced the spatial variation in surface temperatures (fig. 3). Surface temperatures measured at solar noon varied by as much as 35 °C between the canopy-covered and interspace areas. Differences of this magnitude occurred early in the spring and persisted throughout most of the summer and early fall.

Maximum soil temperatures at the 1-cm depths were also dramatically influenced by the sagebrush canopy

and associated litter (fig. 4). Differences between the canopy-covered and interspace areas varied by about 15 °C in the early spring to as much as 30 °C during July and August.

As shown in figure 3, the sagebrush canopy and associated litter had less influence on daily minimum soil temperature at the 1-cm depth than on the daily maximum soil temperature at the same depth. Minimum soil temperatures under the sagebrush canopy were as much as 5 °C higher than in the interspace due to the insulating effect of the plant canopy and associated litter against long-wave radiation losses from the soil surface during
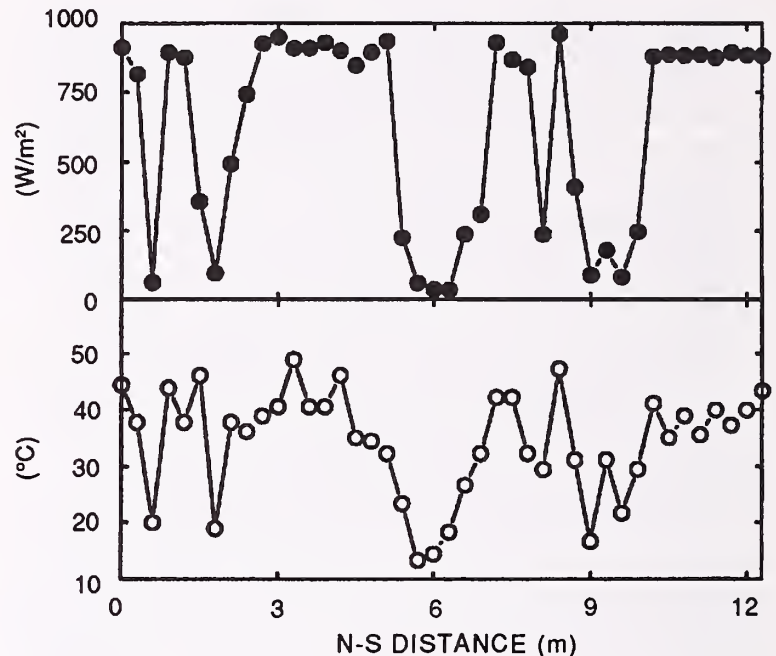

Figure 2—Shortwave solar radiation at the soil surface (W/m²) and temperature (°C) at the ground surface measured at solar noon, March 4, 1989, along a 12.3-m transect at the Quonset site on the Reynolds Creek Experimental Watershed, Reynolds, ID.
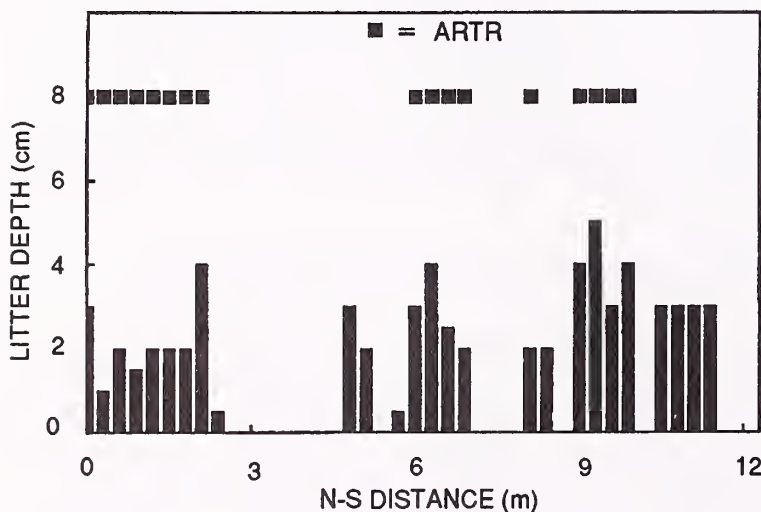

Figure 1—Depth of litter and location of sagebrush plants (ARTR) along a 12.3-m transect at the Quonset site on the Reynolds Creek Experimental Watershed, Reynolds, ID.
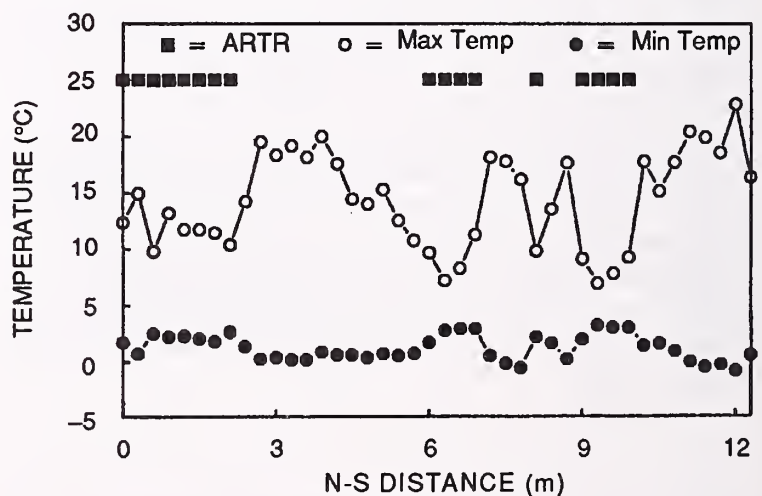

Figure 3—Maximum and minimum soil temperature at the 1-cm depth and the location of sagebrush plants (ARTR) along a 12.3-m transect at the Quonset site on the Reynolds Creek Experimental Watershed, Reynolds, ID.
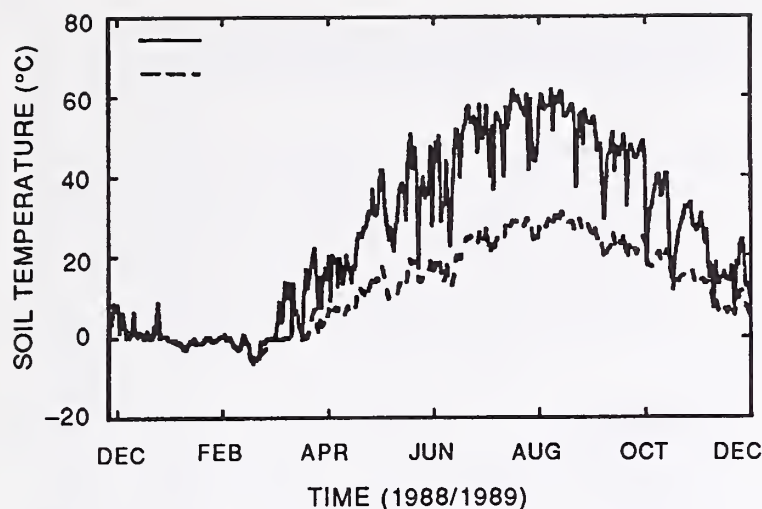
Figure 4—Average daily maximum soil temperature at the 1-cm depth under sagebrush plants and in interspaces between sagebrush plants at the Quonset site on the Reynolds Creek Experimental Watershed, Reynolds, ID.
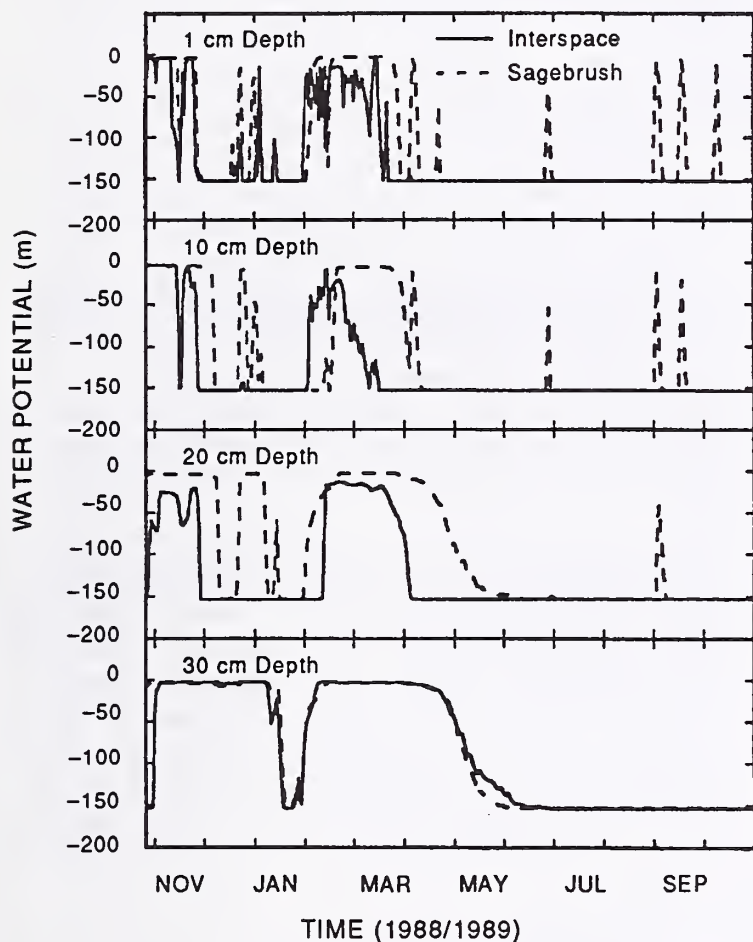
the night. The influence of the sagebrush plant canopy on daily maximum temperature was still evident at the 20-cm soil depth, while canopy influence on daily minimum soil temperatures had all but disappeared at the 10-cm soil depth.

Soil-water potential was also significantly impacted by the sagebrush plants due both to the shading effects of the canopy and insulating effects of the litter (fig. 5). Days during the spring with soil-water tensions less than 1.5 MPa were extended by about 2 weeks at the 1-cm depth and by as much as 8 weeks at the 20-cm depth under sagebrush cover. The influence of sagebrush plants on soil-water potential was barely evident at the 30-cm depth. This extended period of plant-available water under plant canopies may provide microsites for certain plant species to germinate and establish.

To better understand ecological impacts of sagebrush plants on soil temperature, we calculated accumulated growing degree days (GDD) at the 1-cm depth in both the sagebrush and interspace areas (fig. 6). Using 300 GDD as a criteria for some given "biological event," the "event" would have occurred 28 days earlier in the interspace area than under the plant canopy. Such a difference can be important to seed germination, plant establishment, and plant growth and development as well as to other biological activities such as insect growth and development.

The occurrence and timing of particular "biological events" associated with soil-moisture and temperature regimes can be predicted using several years (50 years or more for good results) of soil temperature and water data. However, such data are nonexistent. An alternative is to use model-simulated values as did Wight and others (1984) and Wight and Hanson (1991). Work by
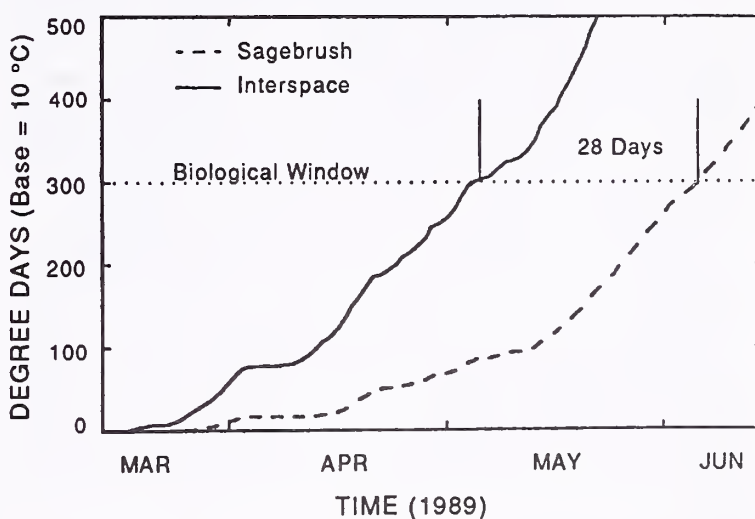

Figure 5—Average daily soil water potential at the 1-, 10-, 20-, and 30-cm depths under sagebrush plants and in interspaces between sagebrush plants at the Quonset site on the Reynolds Creek Experimental Watershed, Reynolds, ID.

Figure 6—Accumulation of degree days at the 1-cm soil depth under sagebrush plants and in the interspace between sagebrush plants at the Quonset site on the Reynolds Creek Experimental Watershed, Reynolds, ID.
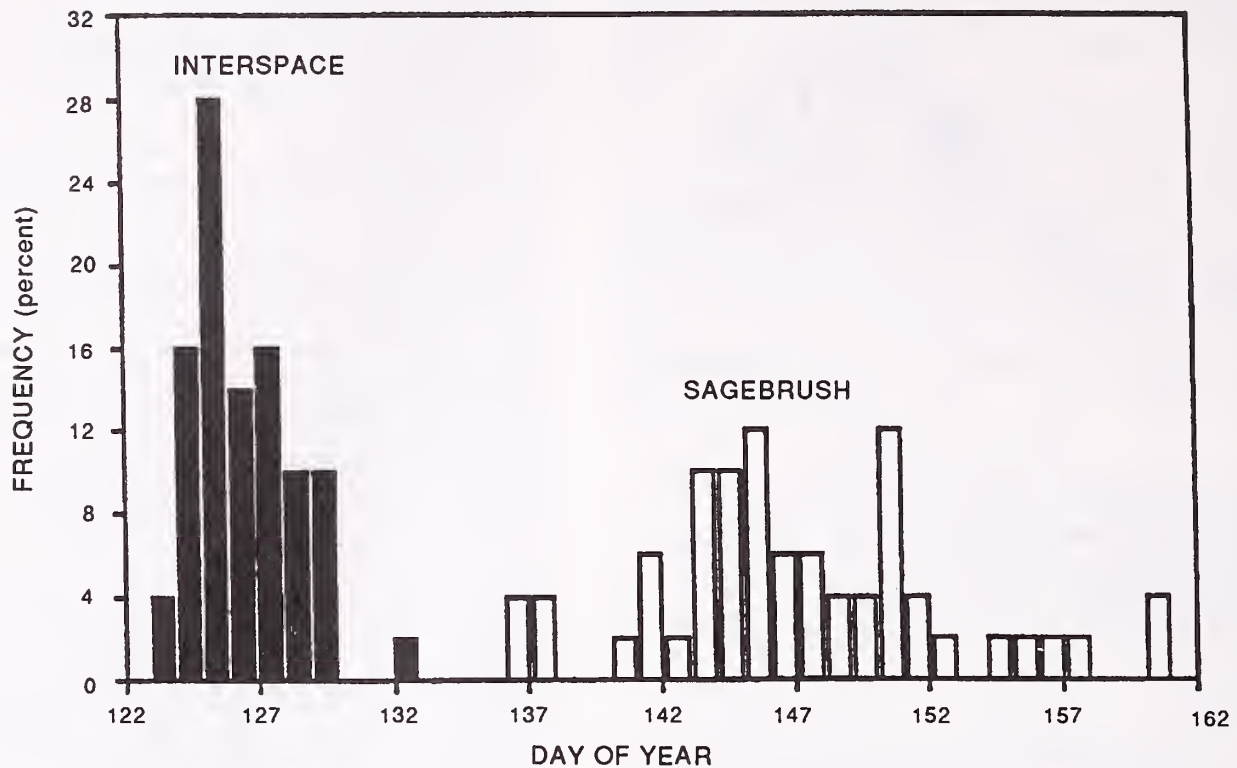
Figure 7—Frequency distribution of the timing of the accumulation of 300 degree days under sagebrush plants and in the interspace between sagebrush plants at the Quonset site on the Reynolds Creek Experimental Watershed, Reynolds, ID.

Flerchinger and Pierson (1991) and Pierson and others (1991) demonstrated that near-surface soil temperature and water regimes could be simulated with reasonable accuracy by the SHAW model. The histogram in figure 7 shows the distribution of days of occurrence of 300 GDD for the sagebrush and interspace areas using a 50-year soil microclimate record simulated by the SHAW model. There is considerable difference between the interspace and sagebrush areas not only in the timing of 300 GDD, but also in the time interval over which the accumulation of 300 GDD occurred. The threshold of 300 GDD was achieved on the average approximately 3 weeks earlier in the interspace compared to under the sagebrush plants. Variation in the accumulation of heat over time was also much less in the interspace than under the plant canopy. This indicates that the timing of "biological events" may be more predictable from year to year at a given location than it is between locations separated by approximately 1 m.

CONCLUSIONS

Shrub canopies can have a significant impact on germination and establishment of understory plants by modifying the near-surface soil microclimate. Sagebrush plant canopies and associated litter can modify near-surface soil temperatures by as much as 30 °C and extend the time interval of plant-available water near the soil surface by as much as 2 weeks compared to the conditions found in the interspaces between plants. Shrubs modify the amount of solar radiation that reaches the soil surface, the amount of long-wave radiation lost by the soil, and the accumulation of litter. All of these factors lead to the existence of a modified microsite, which can allow a greater diversity of plant species to become established on the site.

This kind of information on microclimatic conditions found within different plant communities is needed to better understand how both native and introduced plants become established within a particular plant community. Such information can help us better understand plant community ecology and how weedy plant species, such as cheatgrass, become established and compete in different plant communities. This information can also help develop new seeding strategies and new ways to combat the invasion of weeds, and help us better predict seeding successes.

REFERENCES

Blackburn, W. H. 1975. Factors influencing infiltration rate and sediment production of semiarid rangeland soils in Nevada. Water Resources Research. 11: 929-937.

Blackburn, W. H.; Pierson, F. B.; Seyfried, M. S. 1990. Spatial and temporal influence of soil frost on infiltration and erosion of sagebrush rangelands. Water Resources Bulletin. 26: 991-997.

Eckert, R. E., Jr.; Peterson, F. F.; Belton, J. T. 1986. Relation between ecological range condition and proportion of soil-surface types. Journal of Range Management. 39: 416-420.

Flerchinger, G. N.; Pierson, F. B. 1991. Modeling plant canopy effects on variability of soil temperature and water. Agricultural Forest Meteorology. [In press].

Flerchinger, G. N.; Saxton, K. E. 1989a. Simultaneous heat and water model of a freezing snow-residue-soil system: I. Theory and development. Transactions American Society of Agricultural Engineers. 32: 565-571.

Flerchinger, G. N.; Saxton, K. E. 1989b. Simultaneous heat and water model of a freezing snow-residue-soil system: II. Field verification. Transactions American Society of Agricultural Engineers. 32: 573-578.

Hugie, V. K.; Passey, H. B. 1964. Soil surface patterns of some semiarid soils in northern Utah, southern Idaho, and northeastern Nevada. Soil Science Society of America Proceedings. 28: 786-792.

Nicks, A. D.; Lane, L. J. 1989. Weather generator. In: Lane, L. J.; Nearing, M. A., eds. Water Erosion Prediction Project landscape profile model documentation. NSERL Rep. 2. West Lafayette, IN: National Soil Erosion Research Laboratory, USDA Agricultural Research Service, Purdue University: 2.1-2.19.

Pellant, M. 1990. The cheatgrass-wildfire cycle—are there any solutions? In: McArthur, E. D.; Rumney, E. M.; Smith, S. D.; Tueller, P. T., compilers. Proceedings—symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 11-18.

Pierson, F. B.; Flerchinger, G. N.; Wight, J. R. 1991. Modeling near-surface soil temperature and water on sagebrush rangelands: a comparison of models. Transactions American Society of Agricultural Engineers. [In press].

Pierson, F. B.; Wight, J. R. 1991. Variability of near-surface soil temperature on sagebrush rangeland. Journal of Range Management. 44: 491-497.

Stuart, D. M.; Schuman, G. E.; Dylla, A. S. 1971. Chemical characteristics of coppice dune soils in Paradise Valley, Nevada. Soil Science Society of America Proceedings. 35: 607-611.

Wight, J. R.; Hanson, C. L. 1991. Use of stochastically generated weather records with rangeland simulation models. Journal of Range Management. 44: 282-285.

Wight, J. R.; Hanson, C. L.; Whitmer, D. 1984. Using weather records with a forage production model to forecast range forage production. Journal of Range Management. 37: 3-6.

Wood, M. K.; Blackburn, W. H.; Eckert, R. E., Jr.; Pierson, F. F. 1978. Interrelations of the physical properties of coppice dune and vesicular dune interspace soil with grass seedling emergence. Journal of Range Management. 31: 189-192.

U.S. Department of Agriculture, Forest Service. 1980. An assessment of the forest and range land situation in the United States. FS-345. Washington, DC: Department of Agriculture, Forest Service. 631 p.

U.S. Department of Agriculture, Science and Education Administration, Agricultural Research. 1980. SEA-AR range research assessment, Western United States. Washington, DC: U.S. Department of Agriculture, Science and Education Administration: 5-13.

TO KRIGE OR NOT TO KRIGE: A SPATIAL VARIABILITY STUDY OF A GREAT BASIN SALINE PLAYA

Debra E. Palmquist
Robert R. Blank
James A. Young

ABSTRACT

Coarse-textured soil mounds dotting the edges of playas are characteristic features of the Great Basin. These mounds sustain a sparse, salt-tolerant plant community that consists of allenrolfea (Allenrolfea occidentalis), *greasewood* (Sarcobatus vermiculatus), *and Torrey saltbush* (Atriplex torreyi). *Spatial variability techniques from two different disciplines were adapted to explore patterns of distribution and relationships between these soil mounds and the vegetation occurring on them. From the field of community ecology, Hill's Two-Term Local Quadrat Variance (TTLQV) method was used to explore the distribution of the soil mounds. A mound-clumping pattern was found corresponding to the prevailing wind direction off of the playa. The geological sciences provided methods of semivariograms and kriging for assessing spatial relationships. Semivariograms yielded low and unpredictable variation in differences of soil chemical composition from mound to mound. This suggests a high degree of variance homogeneity in soil chemical composition between mounds. The low and random differences between mounds perhaps point to an adaptive way some of these hardy plants survive in this harsh environment by influencing mound composition.*

INTRODUCTION

One of the main objectives in landscape ecology studies is to understand how plants in a community interact with the landscape on which they are growing. A better understanding of the dynamics of the community can be gained by quantifying vegetation and soil parameters and their interaction with spatial variation over the landscape.

To study the vegetation and soil interactions in a community, it is necessary to quantify their differences and their influences on each other with existing variation in the landscape. Studying soil chemical and physical properties as they vary through space, along with the variation of the differences in plant chemical and physical properties in the same area, allows the formation of a landscape map. This map can chart the spatial relationship of the soil to the variation in plants growing on it, and show how the changes in one affect/interact with the changes in the other.

Statistical correlation, analysis of variance, regression models, and discriminant techniques, to name but a few, have been the standard statistical tools available for such interrelational work. These methods are often unsatisfactory in this context because their main focus is on means comparisons and best-fit predictions independent of their location on the landscape. A method of analysis dealing with variance comparisons on a spatial or landscape location basis would be much more appropriate for the goals in these types of studies.

The field of community ecology provides methods useful in exploring the existence of clumping patterns or random dispersal in spatial data (Ludwig and Reynolds 1988). Hill's Two-Term Local Quadrat Variance method (TTLQV) and the Paired Quadrat Variance method (PQV) are two methods useful in exploring the distribution of data in a study area.

From the field of geostatistics, the techniques of semivariograms and kriging are methods with a basic approach that considers the variance of differences between sample points, unlike the variance of the means with which we are most familiar. Samples in an area are related by position and proximity to their neighbors, and this alone seems to be the overriding factor in the variation of whatever is being measured in both time and space (Clark 1979). Kriging is a technique that would allow us to get a spatial variability map for some plant and soil mound characteristics.

The first step in any spatial variability mapping is to construct the semivariograms. A semivariogram is a measure of the variance of the differences between samples as a function of their distance and direction apart. The main point to this theory is that the variation between two sample points increases until a point is reached where the variances of the observations become independent of one another. It makes intuitive sense that two sample points that are close together have more in common (less variation) than do two points farther apart. So, the variation of the differences between two sample points close together should be less than that of two sample points farther apart.

Soil mounds surrounding edges of saline/alkaline playas are characteristic features in the Great Basin. These mounds have a sand veneer, which apparently greatly increases vegetation cover compared to the playa interface. Most of the vegetation in these areas is concentrated on the dunelike mounds. These communities are on the edge of plant adaptation. They are well represented in Nevada where low precipitation (less than 15 cm/yr) combines with high-salt and alkaline soils to form one of the harshest environments for plant growth and animal sustainability.

Our first objective was to analyze mound dispersal. Are the mounds themselves randomly scattered within the area? If not, is there a discernible distribution pattern in their locations?

Another objective was to quantify how chemical and physical changes of the soil mounds and vegetation vary with respect to different directional gradients from the playa.

METHODS

Our study site, Eagle Valley, is about 90 km east of Reno in the Carson Desert. It is a very saline playa, a dried bed of ancient Lake Lahontan. The landscape is characterized by soil mounds dotting a crusty desert topsoil. The plant species diversity is low in such an inhospitable environment. The four most prevalent plant species are allenrolfea (*Allenrolfea occidentalis*), greasewood (*Sarcobatus vermiculatus*), Torrey saltbush (*Atriplex torreyi*), and saltgrass (*Distichlis stricta*). Most of the vegetation grows only on the soil mounds. The playa interspace is bare except for occasional saltgrass patches.

The study site is a roughly circular area 40 m in diameter and approximately 2 km from the edge of the barren playa. Soil mounds with vegetation (both alive and dead) and bare playa interspace are characteristic of the larger area encompassing the study site.

Angles (degrees) and distances (meters) of the 39 mounds in the site were measured from a central reference point using polar coordinates. A map of the mound locations in the study site was produced by converting polar coordinates to rectangular coordinates. This map was then subsampled in the north-south and east-west directions, plus the diagonals southwest-northeast and southeast-northwest using a 2- by 2-m quadrat. The prevailing wind direction during most of the year is from the playa going from the southwest to the northeast, and a little from west to east.

Plant physical characteristics such as species type, plant height (centimeters), percent cover alive and dead, and biomass were recorded for each of the 39 mounds in the study area. Soil mound physical characteristics measured were mound height above playa (meters), maximum and minimum mound diameter (meters), and soil moisture. Material collected from plant and soil samples was analyzed for chemical composition. Soil mound samples were taken from the crusty top layer of the mounds, and also from 30 cm within the mound. Sample points were composites of four subsamples collected around the entire mound, then analyzed with an ion chromatograph. Plant samples were analyzed for boron (B), calcium (Ca^{+2}), chloride (Cl^-), potassium (K^+), lithium (Li^+), magnesium (Mg^{+2}), sodium (Na^+), ortho-phosphate (PO_4), and sulfate (SO_4^{-2}). Mound soil samples were analyzed for bromide (Br^-), calcium (Ca^{+2}), chloride (Cl^-), EC, potassium (K^+), lithium (Li^+), magnesium (Mg^{+2}), sodium (Na^+), nitrate (NO_3^{-2}), pH, silica (H_4SiO_4), and sulfate (SO_4^{-2}).

Hill's Two-Term Local Quadrat Variance (TTLQV) method was used to assess randomness in mound dispersal with the Paired Quadrat Variance (PQV) method complementing the analysis as a backup check on the TTLQV results (Ludwig and Reynolds 1988). These two methods plot variance as a function of quadrat sample size. If data are randomly scattered in an area, the variance tends to stabilize in a horizontal line (with some fluctuation), as quadrat/block size is increased. Uniform distribution is indicated by regularly spaced, small-amplitude peaks in a horizontal line. Clumping patterns are indicated by irregularly spaced peaks in the graph, where the clumps are separated by a gap of two times the quadrat width.

Semivariograms were plotted for all the plant and soil mound chemical and physical variables measured for each of the four directions. The ideal shape for any semivariogram is that of the spherical or Matheron model (Clark 1979) (fig. 1). Gamma is the semivariogram function (y-axis) and "h" is the distance apart between sample points (x-axis). "C," known as the sill, denotes the point at which the graph levels off, and is also equal to the sample variance. The range of influence of a sample, "a," is the distance at which the observations become independent of one another. The nugget effect is another important model. It is one that describes purely random difference variation fluctuation (Clark 1979).

RESULTS

Plots of variance against increasing block sizes (accomplished by combining adjacent quadrats) for the TTLQV method showed a possibility of mound clumping at block sizes 1, 2, and 6 in the southwest-northeast direction (fig. 2A). The PQV method shows random scattering at block sizes 1 and 2, but tends to confirm mound clumping at block size 6 (fig. 2B). This corresponds to clusters of mounds separated by a gap of approximately 24 m before the next cluster occurs. The east-west direction TTLQV plot shows a clumping of mounds, but of low intensity and not well defined from a block size of 3 to a block size of 7 (fig. 2C). The PQV plot for the same direction shows a gradual increase, but no clear-cut clumping effect (fig. 2D). The north-south direction TTLQV plot suggests a clumping at block size 1, and lesser clumping possibly occurring at block sizes 4 and 6 (fig. 3A), but the PQV does not confirm these results (fig. 3B). The southeast-northwest direction shows a possible clumping effect at block size 1 for the TTLQV plot (fig. 3C), but this is not borne out by the PQV plot of the same direction (fig. 3D).
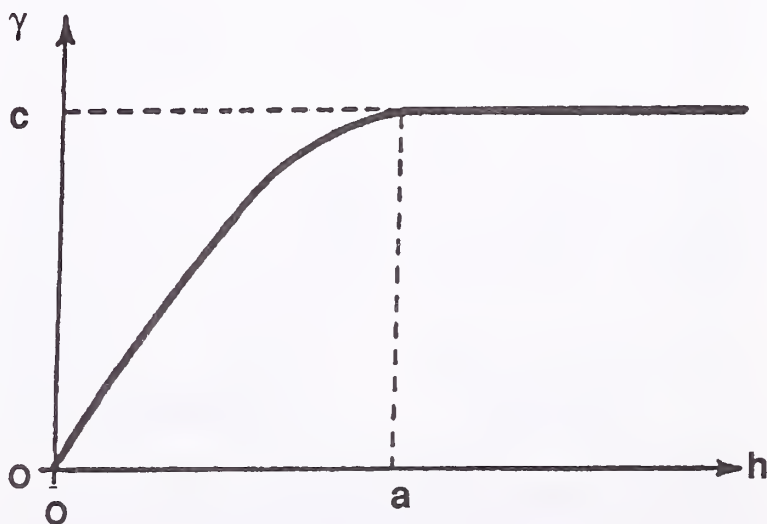

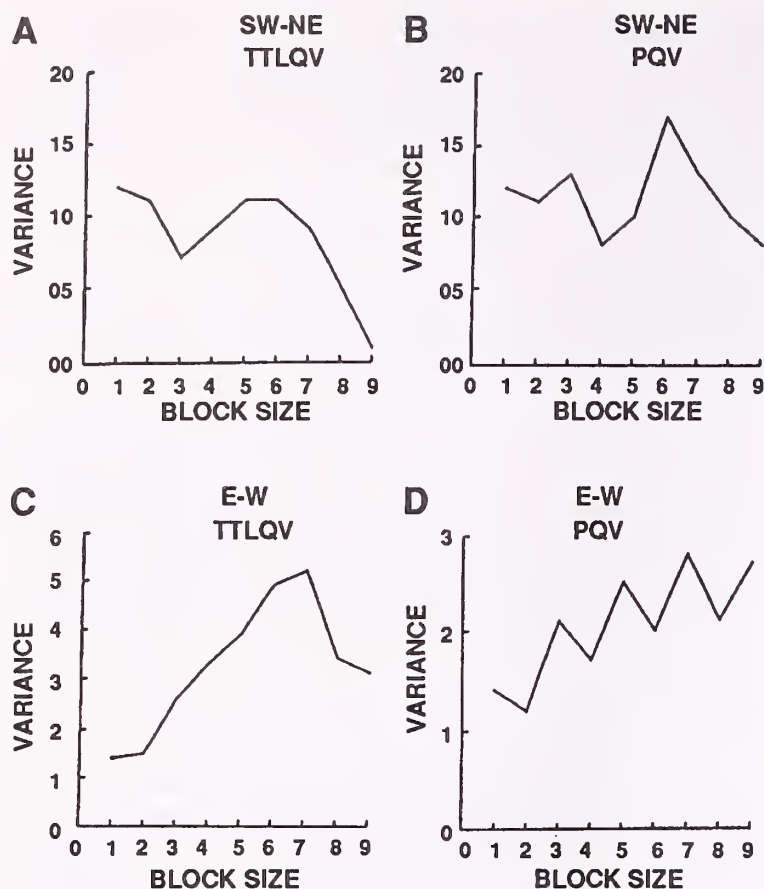Figure 1—Idealized spherical semivariogram model.

Figure 2—Eagle Valley mounds TTLQV and PQV plots for the SW-NE and E-W directions.
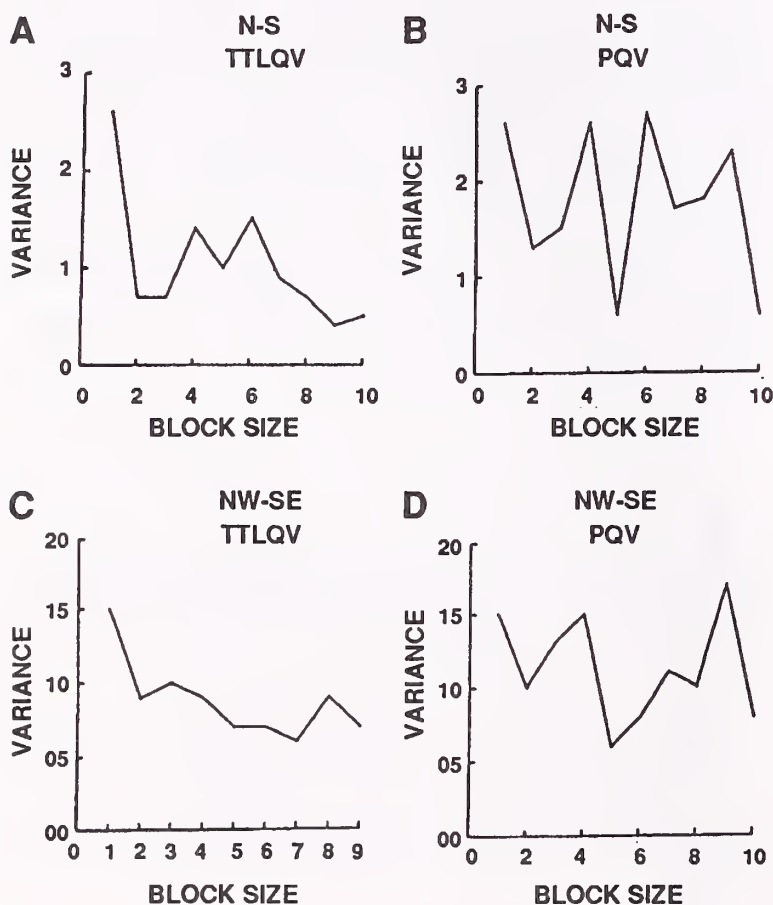

Figure 3—Eagle Valley mounds TTLQV and PQV plots for the N-S and NW-SE directions.

Most of our semivariograms yielded low and unpredictable variation differences in soil and plant chemical composition across the mounds, and also in plant and soil physical characteristics. Chemical composition semivariograms for calcium and sodium are presented for allenrolfea and are contrasted with the same analysis for the soil mounds. Allenrolfea was by far the most prevalent plant growing on the mounds in Eagle Valley.

Starting at a distance of 5 m apart, variation of differences between allenrolfea plants in terms of calcium concentration (ppm) rises spherically then levels off at a point when distances between plants are approximately 25 m in the east-west direction (fig. 4A). The data points are widely scattered from the fitted equation, but the data generally follow the hypothesis of increasing variation of differences as the plants are spaced farther apart. In the north-south direction (fig. 4B), a spherical relationship exists until the plants are 20 m apart, then rapidly decomposes into random variation—the nugget effect (Clark 1979).

Only random variation of differences occurred in calcium concentration for the soil mound crust samples over the study area in all four directions. However, the deep soil samples showed a spherical relationship from approximately 3 m apart to 20 m apart in the southwest-northeast direction (fig. 4C). In the southeast-northwest direction (fig. 4D), there was a spherical and cyclic relationship between calcium concentration variation of differences and the distance apart of the deep soil samples.

Sodium was an interesting chemical to study, both in the vegetation and the soil mounds, because of the interest in how these plants adapt to such saline conditions. In the southeast-northwest direction, sodium concentration (ppm) variation of differences for allenrolfea shows a nugget effect until the plants reach distances of approximately 13 m apart (fig. 5A). Then an almost linear, but steeply sloping, spherical model describes how allenrolfea sodium concentration differences are related to how far apart the plants are from each other. A more typical spherical relationship for allenrolfea sodium concentration differences is shown for the north-south direction (fig. 5B). It appears that the variations in differences become independent of each other when the plants are 17 m and more apart, but up to that point the variation increases spherically.

The only soil mound sodium semivariogram to show a relationship other than a pure nugget effect was in the north-south direction for the soil crust samples (fig. 5C). This looks like a cyclic relationship, with one spherical model fitting from 2 to 20 m, and the other describing variation of differences in soil crust sodium samples when mounds are 20 to 35 m apart.

DISCUSSION

The clumping pattern of mounds occurring approximately every 24 m in the southwest-northeast direction suggests an interaction between mound formation and the winds that blow off the playa. More indepth work needs to be done to further quantify this relationship. There probably is a plant establishment factor involved with initial mound formation that occurs when winds deposit eolian material, thereby creating favorable seedbed conditions for early plant recruitment off the playas (Blank and others, these proceedings).
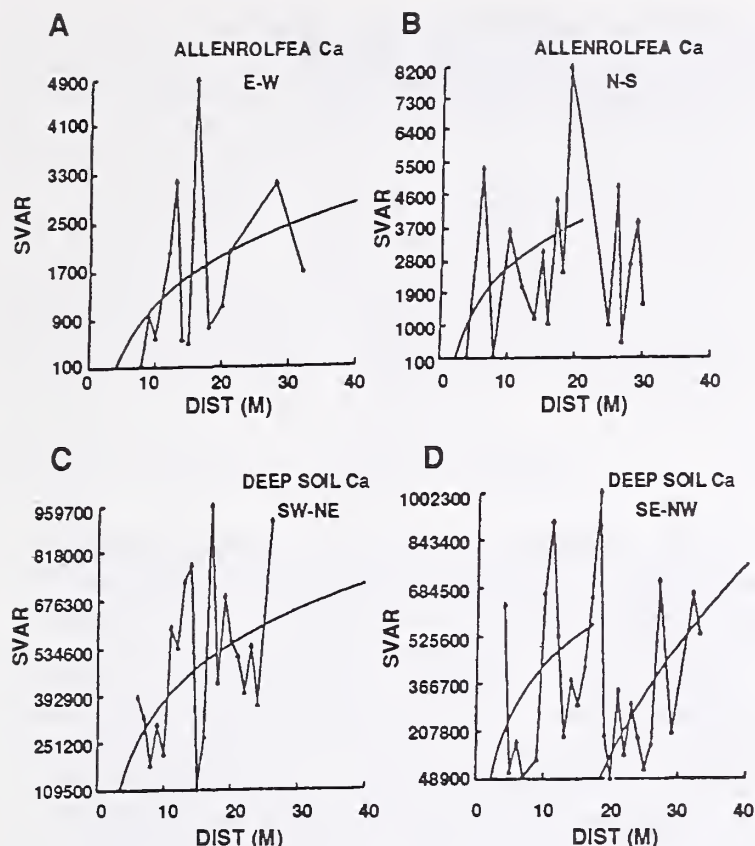
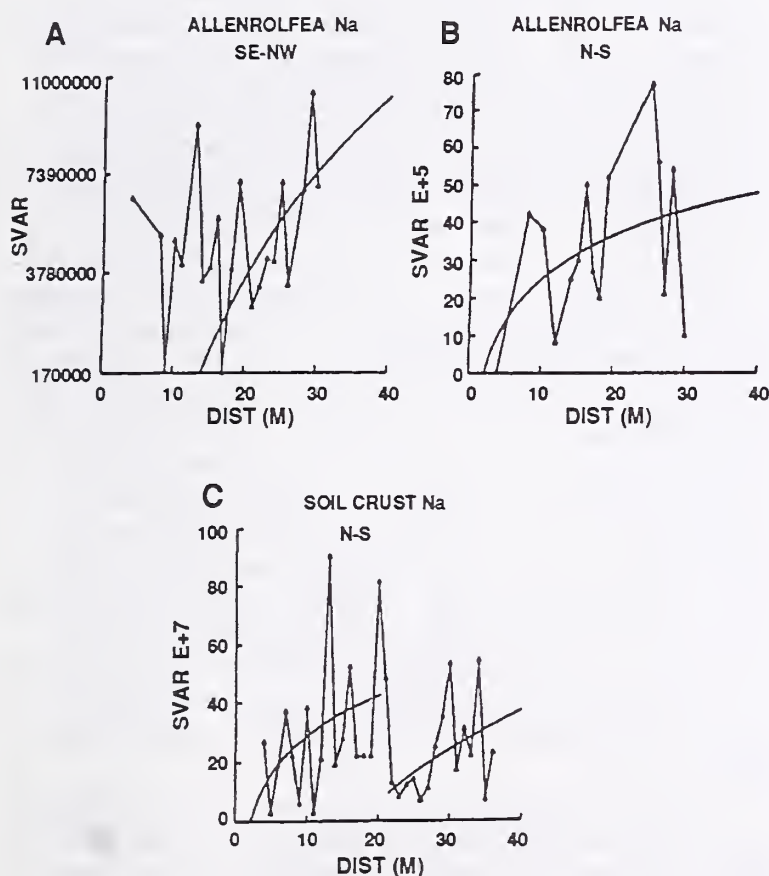**Figure 4**—Calcium concentration semivariograms for *Allenrolfea occidentalis* and deep soil samples.

Figure 5—Sodium concentration semivariograms for *Allenrolfea occidentalis* and soil crust samples.

Most of the semivariogram analyses yielded extremely variable results. This could be due to a number of factors: (1) the small size of the study area; (2) the fact that only mound soils were sampled (none from the playa interspace); and (3) a high degree of variance homogeneity exists between the mounds (differences between the mounds are small and random), making a variance relationship with distance a fruitless endeavor.

Although calcium semivariograms for the plant species allenrolfea showed modelable results in the east-west and north-south directions, these were not matched by any of the crust mound samples for calcium or the deep mound soil samples that did show relationships, albeit in the southwest-northeast and southeast-northwest directions.

Semivariogram results for sodium concentration variation of differences are worth further investigation. The same general spherical model for the same distance ranges (2 to 20 m) was found for both allenrolfea plants and soil crust samples in the north-south direction. Perhaps, through time, the plants are modifying the top layers of the soil mounds on which they grow (Blank and others, these proceedings).

Overall, the semivariograms proved to be too ill-defined due to low and random variability. Without clearly definable semivariogram functions, continuing with any kind of kriging analysis would be very inaccurate, and the results unusable. Since the variability between mounds is very low and the variation of differences is more random than anything else, it appears that the mounds are spatially homogeneous in their chemical composition properties and also in their physical characteristics. A hypothesis is offered that the vegetation influences mound chemical and physical properties to enhance growth and sustainability in these types of communities (Blank and others, these proceedings).

CONCLUSIONS

Eagle Valley is a playa characteristic of areas in the Great Basin that are on the edge of plant adaptation to saline and alkaline environments. This type of environment, although seemingly inhospitable, is used as a limited grazing resource and is increasingly exposed to disturbances where revegetation techniques may need to be implemented in the future. Using techniques from the fields of community ecology and geostatistics, along with the standard arsenal of both parametric and nonparametric techniques already in use, we can try to get a better grasp of the dynamic interactions between plants and the landscape on which they grow. Future considerations include mapping the relationship of a single soil mound's chemical composition and comparing it to the chemical properties of the vegetation growing on it. We hope to be able to produce clearly defined semivariograms for this situation so that we can successfully krige and co-krige our results to get a usable map of a single-mound ecosystem.

REFERENCES

Clark, I. 1979. Practical geostatistics. London: Applied Science Publishers. 129 p.

Ludwig, John A.; Reynolds, James F. 1988. Statistical ecology: a primer on methods and computing. New York: John Wiley & Sons. 337 p.

RESPIRATION AND GROWTH IN SEEDLINGS OF COLD-DESERT SHRUBS

Bruce N. Smith
C. Mel Lytle
Lee D. Hansen
Josef Lipp
Hubert Ziegler

ABSTRACT

Plants from geographic races (subspecies) of four species of cold-desert shrubs (Artemisia tridentata, Atriplex canescens, Chrysothamnus nauseosus, *and* Kochia prostrata) *were grown from seed in the greenhouse. After 4 months, the seedlings were compared for shoot and root growth. No correlation between growth and carbon and hydrogen isotopic values was found. However, a robust correlation existed between growth and plant respiration as measured by microcalorimetry.*

INTRODUCTION

Some plants grow more rapidly than even their own close relatives. It would be of great practical importance to understand the reasons for growth differences. Photosynthetic differences exist but do not seem to be correlated with growth rate (Frank and others 1986). Water use efficiency, especially as measured by carbon isotopes in C_3 plants, has been correlated with productivity (Condon and others 1987; Farquhar and others 1982). Dark respiration has been said to be both negatively correlated (Amthor 1989) and positively correlated (Hay and Walker 1989) with growth. Clearly more needs to be done.

Several species of cold-desert shrubs have accessions, geographic races, or subspecies that exhibit growth differences even when grown in a common garden (McArthur and Welch 1982; Stutz and others 1975). Our experience has been that growth differences are often exhibited in young seedlings. We therefore did this preliminary study to determine the future direction for our research on the problem of plant growth.

MATERIALS AND METHODS

Seed was obtained from Durant McArthur at the Intermountain Research Station's Shrub Science Laboratory in

Provo, UT, and from Howard Stutz of the Botany Department at Brigham Young University. Seed was planted in soil in the greenhouse and watered well. After 4 months the plants were harvested and data were taken.

Artemisia tridentata ssp. *wyomingensis* was seed collected by Susan Meyer in 1988 at Prospect Point, WY, and shown to be 4n. Subspecies *tridentata* was seed collected in 1986 from Snow Field Station, Ephraim, UT (Accession U 74). The original population was from Dove Creek, Dolores County, UT, and shown to be 2n. Subspecies *vaseyana* was 1987 seed from Accession U 1. The original population was from Hobble Creek, Utah County, UT, and shown to be 2n. F_2 seed from an F_1 crossing block represented a hybrid from a cross of the Dove Creek and Hobble Creek populations (1987 seed) shown to be 2n.

Atriplex canescens ssp. *angustifolia* seed was collected in 1987 from Tucson, AZ, and shown to be 2n. Subspecies *gigantea* seed was collected in 1989 at Jericho Sand Dunes, UT, and shown to be 2n. Subspecies *dulcea* was collected in 1991 from Tooele, Tooele County, UT, and shown to be 6n. A collection of seed from Lisbon Valley, San Juan County, UT, was made in 1990 and shown to be 4n. All of the *Atriplex* seed was collected by Howard Stutz.

Chrysothamnus nauseosus ssp. *hololeucus* was collected in 1988 in Nephi Canyon, UT, and shown to be 2n. Subspecies *viridulus* was collected in 1986 in Lee Vining, CA, and shown to be 2n. Subspecies *graveolus* (U-4-90) was collected at the Snow Field Station; the original site was Leeds, UT. Subspecies *nauseosus* (U-1-90) was also collected from the Snow Field Station; the original site was Terry, MT. All of the *Chrysothamnus* collections were by Susan Meyer.

Kochia prostrata, U 10 accession (PI 356826) from the Soviet Union, was grown in Hobble Creek, UT, harvested in 1987, and shown to be 6n. The U 11 accession (PI 356819) was grown in Hobble Creek, UT, harvested in 1988, and shown to be 4n. The U 2 accession (PI 314929) 'Immigrant' from the Soviet Union was 1987 seed grown at the Los Luna Plant Materials Center in New Mexico and shown to be 2n.

Shoot and root length were measured with a meterstick. Dry weight was obtained after drying for 24 hours at 65 °C. Dried shoot material was combusted and analyzed for carbon and hydrogen isotopes on an isotope ratio mass spectrometer with results expressed as o/oo (parts per thousand) relative to the usual standards: Peedee Belemnite (PDB) or Standard Mean Ocean Water (SMOW) (Smith and Ziegler 1990). Live and healthy shoot tissue was used

for the metabolic measurements. About 50 mg fresh weight (9 mg dry weight) of leaf tissue was put in each chamber of the Hart Scientific model 7707 differential scanning calorimeter. Three tissue samples could be examined simultaneously in three different chambers. Metabolic heat rates were measured using the isothermal operating mode of the calorimeter at 25 °C. Heat rate measurement was made continuously until a constant heat flow rate indicated that the sample and chamber had attained a steady state (approximately 45 minutes). The heat rates obtained are a measure of the metabolic rates and are expressed as microwatts (μW) (Criddle and others 1989).

RESULTS AND DISCUSSION

Differences in growth rate have been well established between accessions and subspecies of big sagebrush (*Artemisia tridentata*) (McArthur and Welch 1982). Photosynthetic rates showed a great deal of variation between accessions but no correlation with growth rate. Subspecies of big sagebrush grown in a common garden showed consistant differences in new growth each year. Small differences in carbon isotopic values were also consistantly noted as shown in table 1 (Frank and others 1986). Plants with lower growth rates showed a larger isotopic fractionation (more negative $\partial^{13}C$ values) than plants with faster growth rates. The changes were small and would amount to an isotopic difference of 1 o/oo for each differential 15.5 cm of new growth each year. Big sagebrush is a C_3 plant, and several workers have shown a strong positive correlation between biomass production and stable isotopes for C_3 plants (Condon and others 1987; Martin and Thorstenson 1988).

Fourwing saltbush (*Atriplex canescens*) has a number of ploidy races that differ in growth rate (Stutz and others 1975), even when grown in a common garden. As shown in table 2, the $4n$ race had a much higher rate of photosynthetic carbon fixation than the $2n$ race. In turn, this was

Table 1—Growth rate and carbon isotopic values for three subspecies of big sagebrush (*Artemisia tridentata*) grown in a common garden in Springville (Frank and others 1986)

Subspecies	Stem length	$\partial^{13}C$ (o/oo vs PDB)
	cm/yr	
tridentata	28.78	−27.59
vaseyana	23.33	−28.00
wyomingensis	20.10	−28.15

Table 2—Photosynthesis and carbon isotopic values for two chromosomal races of fourwing saltbush (*Atriplex canescens*) grown in a common garden in Provo

Chromosomal race	Photosynthesis	$\partial^{13}C$ (o/oo vs PDB)
	mg CO_2/g/h	
$2n$	22.6	−18.95
$4n$	36.1	−15.35

associated with a large (3.6 o/oo) fractionation in carbon isotopes. Fourwing saltbush is a C_4 plant, so the water-use efficiency model (Farquhar and others 1982) to explain isotopic fractionation does not apply here. The water-use efficiency model assumes that carbon isotopic fractionation is associated with photosynthetic carbon fixation. In reality, many events can influence isotopic fractionation.

Seed from several accessions and subspecies of cold-desert shrubs was planted and grown in the greenhouse for 4 months. As seen in table 3, *Atriplex* seedlings exhibited

Table 3—Shoot and root growth of 4-month-old greenhouse-grown seedlings of subspecies of *Artemisia tridentata, Atriplex canescens, Chrysothamnus nauseosus,* and *Kochia prostrata*

Subspecies		Shoot Length	Shoot Dry wt.	Root Length	Root Dry wt.	Shoot/root Length	Shoot/root Dry wt.
		cm	mg	cm	mg	cm	mg
Artemisia tridentata							
wyomingensis	4n	4.66	32.72	10.60	7.12	0.44	4.60
tridentata	2n	7.24	60.28	10.43	8.44	.69	7.14
vaseyana	2n	7.57	81.14	13.80	13.61	.55	5.96
F$_2$ hybrid	2n	7.65	92.93	16.27	18.17	.47	5.11
tridentata x vaseyana							
Atriplex canescens							
angustifolia	2n	22.60	131.75	9.33	8.41	2.42	15.67
gigantea	2n	29.22	142.91	6.64	11.52	4.40	12.41
Chrysothamnus nauseosus[1]							
hololeucus	2n	9.79	28.2	—	—	—	—
viridulus	2n	19.74	63.3	—	—	—	—
Kochia prostrata							
U 10	6n	8.15	40.55	9.57	5.99	.85	6.77
U 11	4n	9.01	28.11	7.69	4.02	1.17	6.99
U 2	2n	11.24	44.39	9.82	7.03	1.14	6.31

[1]Root collections not made for *Chrysothamnus*.

Table 4—Metabolic heat and carbon and hydrogen isotopic ratios from 4-month-old greenhouse-grown seedlings of subspecies of *Artemisia tridentata*, *Atriplex canescens*, *Chrysothamnus nauseosus*, and *Kochia prostrata*. Subspecies are listed in order of increasing growth rate

Subspecies		Metabolic heat	$\partial^{13}C \pm SE$ (o/oo vs PDB)	$\partial D \pm SE$ (o/oo vs SMOW)
		µW/mg		
Artemisia tridentata				
wyomingensis	4n	8.46	−34.91 ± 0.05	−79.3 ± 6.0
tridentata	2n	10.56	−35.01 ± 0.20	−84.4 ± 5.2
vaseyana	2n	10.74	−34.96 ± 0.19	−85.3 ± 4.2
F₂ hybrid	2n	12.69	−34.21 ± 0.11	−80.6 ± 2.4
tridentata x vaseyana				
Atriplex canescens				
dulcea	6n	19.08		
Lisbon Valley	4n	15.39		
angustifolia	2n		−19.00 ± 1.01	−65.6 ± 6.9
gigantea	2n	14.93	−18.99 ± 0.38	−69.3 ± 4.4
Chrysothamnus nauseosus				
hololeucus	2n	7.50	−34.87 ± 0.34	−94.3 ±14.5
graveolus		11.47		
nauseosus		18.01		
viridulus	2n		−36.44 ± 0.04	−74.7 ± 5.7
Kochia prostrata				
U 10	6n	9.36	−23.88 ± 1.41	−68.4 ± 1.7
U 11	4n	14.27	−18.28 ± 0.58	−59.2 ± 1.8
U 2	2n		−23.95 ± 1.62	−83.5 ± 0.9

more growth than did the other species. *Atriplex* also produced much more shoot biomass than root biomass with shoot/root ratios from two to 10 times as great as the other species. Root collections were not made for *Chrysothamnus*. Quantitative recovery of roots even from this very light soil mix is difficult. Thus, root biomass appeared to be much less than shoot biomass for all of the plants. Root length exceeded shoot length for all of the *Artemisia* seedlings and was near unity (shoot/root = 1) for *Kochia*. It is important to note that subspecies that grow most rapidly in the field also grew most rapidly as seedlings. There definitely appears to be a genetic component to growth differences between shrubs.

Isotopic ratios, as seen in table 4, did not show significant differences between subspecies. We were surprised at this given the differences (even though small) seen in the field-grown subspecies (tables 1 and 2). Carbon isotopic values are several per mil more negative for greenhouse-grown material than for plants grown outdoors due to the higher concentration of CO_2 of respiratory origin in the greenhouse. The C_4 plants, *Atriplex* and *Kochia*, showed typical carbon and hydrogen isotopic differences from the C_3 species, *Artemisia* and *Chrysothamnus* (Smith and Ziegler 1990). The only significant isotopic differences were in *Chrysothamnus* and *Kochia*. Isotopes of organic hydrogen were examined to determine possible differences in water-use efficiency between subspecies. No significant differences were found. Further study is needed to determine the nature of the differences between these plants.

Metabolic heat did show a strong, positive, and very robust correlation with seedling growth. Due to lack of growth data, that is not clear for *Atriplex*, but it is certainly the

case for all of the other species and subspecies examined. That plants committed to more-rapid growth have higher metabolic heat rates is in agreement with published work on physiology (Hay and Walker 1989) and salt stress (Criddle and others 1989). Different results reported by Amthor (1989) can be attributed to use of mature, nonmeristematic tissue. It now seems possible to predict relative rates of growth on a long-term basis from metabolic measurements on perennial meristematic tissue. Obviously, the preliminary results reported here are but the beginning of that which needs doing.

REFERENCES

Amthor, Jeffrey S. 1989. Respiration and crop productivity. New York: Springer-Verlag. 215 p.

Condon, A. G.; Richards, R. A.; Farquhar, G. D. 1987. Carbon isotope discrimination is positively correlated with grain yield and dry matter production in field-grown wheat. Crop Science. 27(5): 996-1001.

Criddle, Richard S.; Hansen, Lee D.; Breidenbach, R. William; Ward, Michael R.; Huffaker, Ray C. 1989. Effects of NaCl on metabolic heat evolution rates by barley roots. Plant Physiology. 90: 53-58.

Farquhar, G. D.; O'Leary, M. H.; Berry, J. A. 1982. On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. Australian Journal of Plant Physiology. 9: 121-137.

Frank, C. T.; Smith, B. N.; Welch, B. L. 1986. Photosynthesis and growth in different accessions of big sagebrush (*Artemisia tridentata* Nutt.). In: McArthur, E. D.; Welch, B. L., eds. Proceedings—symposium on the biology of

Artemisia and *Chrysothamnus*; 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 332-335.

Hay, Robert K. M.; Walker, Andrew J. 1989. An introduction to the physiology of crop yield. New York: Longman Scientific and Technical. 292 p.

Martin, B.; Thorstenson, Y. R. 1988. Stable carbon isotope composition, water use efficiency, and biomass productivity of *Lycopersicon esculentum*, *Lycopersicon pennellii*, and the F_1 hybrid. Plant Physiology. 88: 213-217.

McArthur, E. D.; Welch, B. L. 1982. Growth rate differences among big sagebrush (*Artemisia tridentata*) accessions and subspecies. Journal of Range Management. 35: 396-400.

Stutz, Howard C.; Melby, James M.; Livingston, Gordon K. 1975. Evolutionary studies of *Atriplex*: a relic gigas diploid population of *Atriplex canescens*. American Journal of Botany. 62(3): 236-245.

PLANT-SOIL RELATIONSHIPS OF GREASEWOOD, TORREY SALTBUSH, AND ALLENROLFEA THAT OCCUR ON COARSE-TEXTURED MOUNDS ON PLAYAS

Robert R. Blank
Debra E. Palmquist
James A. Young

ABSTRACT

A veneer of sand overlying saline playa sediment radically affects plant distribution and productivity. In the Lake Lahontan Basin of northwestern Nevada, where annual precipitation averages less than 15 cm, these sand veneers are productive sites with a richness of vegetation typically found on more mesic sites. As the sand veneer thins near barren playa surfaces, however, vegetation is more sparse and is characterized by salt-tolerant shrubs and grasses. Plant-soil relationships at this playa-sand veneer interface near Fernley, NV, were studied. The vegetation both captures eolian material and protects former beach and offshore bar deposits to form coarse-textured mounds. These mounds support a floristically simple community dominated by allenrolfea (Allenrolfea occidentalis [Wats.] O. Kuntze) with lesser amounts of greasewood (Sarcobatus vermiculatus [Hoop.] Torr.), and Torrey saltbush (Atriplex torreyi [Wats.] Wats.). The soil-solution chemistry was characterized for: mound rooting zone of each shrub, barren regions on mounds, and unvegetated intermound sediment. Data show that the mounds are extremely saline, more saline than unvegetated mound interspaces. Moreover, there were significant ($P \leq 0.05$) differences in the soil-solution chemistry among the shrubs, which suggests the shrubs have modified the soil solution through elemental cycling. This information, combined with site geomorphology and plant distribution patterns, suggests that the shrub communities on the mounds are cyclic in nature. During environmentally optimal periods, recruitment occurs. Reduction of wind velocity by plant growth allows the deposition of eolian material to form a mound. Long-term plant cycling of salts leads to unfavorable soil conditions, which results in plant death and mound erosion, thus completing the cycle.

INTRODUCTION

The Pleistocene epoch in the Lake Lahontan Basin was marked by oscillating climate (Russell 1895). During glacial advances, the climate was cool and moist, forming extensive interconnected pluvial lakes in the basins (Mifflin and Wheat 1979). Drying during interglacial times created saline playas. This fluctuating climate was and is a stimulus for plant migration and adaptation (Billings 1945). Nowhere is this stimulus more evident than at the borders of playas. Here, striking variations in salinity and soil texture occur in a relatively narrow band. Thus, a myriad of plant communities exist in near proximity, yet they are very different in adaptive characteristics to soil salinity. This is readily apparent where offshore sandy bars and eolian sand form a veneer over more saline sediments. When the sand veneer is thick, these zones possess a richness of vegetation more characteristic of mesic environments. However, the environment becomes harsher as sand veneers thin near the borders of barren playas.

Salt-tolerant plants at the edge of their tolerance to environmental condition, including allenrolfea (*Allenrolfea occidentalis* [Wats.] O. Kuntze), greasewood (*Sarcobatus vermiculatus* [Hoop.] Torr.), Torrey saltbush (*Atriplex torreyi* [Wats.] Wats.), and shadscale (*Atriplex canescens* [Pursh.] Nutt.), survive as islands of vegetation. These species occur on coarse-textured mounds, which dot largely unvegetated interspaces. We are trying to understand how plants survive in this environment. Our working hypothesis postulates that the mounds are less saline than the interspaces and, therefore, provide a more favorable environment for plant growth and recruitment of new plants. This paper reports on our research concerning plant-soil relationships in this harsh environment.

MATERIALS AND METHODS

The study area is at the Eagle Valley Embayment of the Lake Lahontan Basin, which is approximately 90 km east of Reno, NV, on Interstate 80. During pluvial periods, the Truckee River, exiting the Sierra Nevada, deposited deltaic sands near Fernley, NV, about 7 km west of the study area. These deposits, as well as offshore bars, colluvial sediments from the surrounding highlands, beach deposits, and the eolian reworkings of these deposits are a factor in the development of plant communities in the study area. At

maximum lake level, the study area was covered with over 120 m of water. The present climate is arid; precipitation averages 100 mm per year with a large variance. Most rainfall occurs in the winter and spring as Pacific moisture passes over the Sierra Nevada mountains. Intense spring and summer thunderstorms are rare. One witnessed by the first author caused extensive flooding on the playa with much coarse sediment movement in the washes. Intense winter and spring winds can deflate and deposit considerable material. Several mounds and adjacent unvegetated playa were excavated with a backhoe to facilitate soil description and collection of soil horizons for characterization. Standard procedures were used to describe and collect soil materials (Soil Survey Staff 1984, 1990). Material was lightly crushed to pass a 2-mm sieve, and all characterization procedures were performed on this material. Organic carbon was determined by the Walkley-Black method (Nelson and Sommers 1982). The pipette method was used to determine particle size distribution (Gee and Bauder 1986). The ammonium acetate method was used to determine cation exchange capacity (Soil Survey Staff 1984). Sand-sized material, saved from particle size analyses, was examined with a petrographic microscope to determine its mineralogy.

Six replicate coarse-textured mounds each supporting allenrolfea, greasewood, and Torrey saltbush were randomly located and sampled in June of 1989. Composite soil samples within their mound rooting zone were collected for each shrub species at each replicate mound. We also collected composite soil samples for: (1) barren mound surfaces, 2-10 cm; (2) playa sediment beneath the mound; and (3) interdune sediment immediately adjacent to the mounds, 0-10 cm. A saturation extract was prepared for each sample and other collected material (U.S. Salinity Laboratory Staff 1954). Electrical conductivity was measured with a salinity drop tester. The following soluble species were measured in the saturation extract: (1) lithium, sodium, potassium, chloride, and sulfate by ion chromatography with detection by suppressed conductivity (Weiss 1986); (2) bromide and nitrate by ion chromatography with spectrophotometric detection at 210 nm (Weiss 1986); (3) silica by silicomolybdous acid procedure (Weaver and others 1968); and (4) boron by azomethine-H colorimetry (John and others 1975). The data were analyzed by a one-way analysis of variance with significant differences among categories discerned by Fisher's protected LSD.

MOUNDS AND PLANT COMMUNITIES

Mounds occur in a narrow band at the interface of a large, open unvegetated playa and the surrounding uplands. Dotting a barren landscape, the mounds are islands of vegetation. Ocular estimates from the study area indicate the mound zone contains approximately 30 percent mounds and 70 percent unvegetated interspaces. From the measurement of over 50 mounds, the average dimensions were: 3.1 m (s.d. = 1.8) in length, 1.9 m (s.d. = 1.1) in width, and 0.30 m in height at the highest point. No variance is given for mound height because it was difficult to discern where mound material merged into underlying playa sediment. Mounds closest to the open playa are dune shaped as though eolian in origin; however, mound stratigraphy and particle size analyses (data not shown) indicate that they are composite; part eolian and part offshore bar and beach sediment. Mounds farther from the open playa are slightly higher and appear as a complex of several mounds that have, over time, coalesced. The interspaces among mounds exhibit a polygonal cracking pattern and are generally finer textured than mounds. At many locations, the interspaces are identical in character to playa sediments. A typical mound soil profile is shown in table 1. The mounds all have a surface crust containing numerous salt crystals. The hardness of this crust and the amount of salt efflorescence vary greatly over the year. Mound soil horizons were subdivided based on the amount and type of accessory salts and root distribution. A transitional zone with an intermediate texture (table 1, layer 6) is typical. Layer 7 is typical of playa sediment, which contains fine laminar layers characteristic of lacustrine lake sediments. Playa sediments are generally in an anoxic state as indicated by the presence of pyrite. The water table in the study area is at a depth of about 1 to 2 m. All soil horizons contain free calcium carbonate. The sand-sized mineralogy of the mounds and recent eolian material is dominantly feldspar and quartz; playa sediments consist of a cemented diatomaceous material. This fact indicates mounds themselves are not formed from eroded playa sediments, but from sands of Sierran granodiorite. The playas' smooth surfaces make them generally immune from deflationary events save for salt efflorescences, which are readily moved by wind.

The dominant mound shrub is allenrolfea. Its deep green color in contrast to the light brown to gray unvegetated mound interspaces is striking. Mounds near the open playa are vegetated almost exclusively by allenrolfea. Farther

Table 1—Pedon description of typical allenrolfea mound[1]

Layer	Depth	Munsell color	Dry consistency	Particle size distribution			Organic carbon	Effervescence in HCl	Cation exchange capacity	Root abundance
				sand	silt	clay				
	cm	Dry		---------- Percent ----------					meq/100 g	
1	0-2	2.5Y 6/3	slightly hard	79	7	14	0.32	strong	8.1	absent
2	2-20	2.5Y 6.5/2	slightly hard	76	13	12	.20	strong	7.3	common
3	20-76	2.5Y 6.5/2	soft	86	6	9	.65	strong	5.5	few
4	76-86	2.5Y 6/2	slightly hard	—	—	—	.21	strong	9.2	absent
5	86-122	5Y 6/3	slightly hard	68	16	16	.74	weak	11.3	common
6	122-157	2.5Y 7/2	slightly hard	48	28	24	.20	strong	14.6	few
7	157+	2.5Y 7.5/2	hard	8	55	37	.45	violent	33.2	absent

[1]Soil described from top of mound.

Table 2—Saturation extract values of composite soil samples for the various categories

Category	Electrical conductivity	Chloride	Bromide	Nitrate	Sulfate	Lithium	Sodium	Potassium	Silica	Boron
	dS/m					µg/mL				
Bare	120a[1]	56,000a	90ac	505a	3,750ad	121a	33,300a	2,584	6.5a	289a
Interdune	59b	20,700b	154a	58b	924bcd	68ac	14,700b	2,271	6.5a	132bc
Playa beneath dune	43b	14,500b	166a	37b	1,320ac	48bc	11,600b	450	16.4b	60b
Greasewood	105ac	51,800ac	1,027bc	273ac	6,090d	93ac	30,800ac	4,002	7.9a	277ac
Allenrolfea	64bc	21,200b	241a	204bc	3,880ad	42bc	15,800bc	946	8.5a	279ac
Torrey saltbush	56bc	21,100bc	135a	26bc	3,590acd	44bc	14,300bc	1,554	9.1a	151abc
Seawater[2]		19,000	65			0.18	10,500	380		4.6

[1]Column values followed by the same letters are not significantly different based on Fisher's protected LSD at the 5 percent level.
[2]Seawater data from page F-154, Handbook of Chemistry of Physics, 64th edition.

back from the open playa zone, other shrubs coexist with allenrolfea on the same mound. The most prevalent of the shrubs are greasewood and Torrey saltbush. Both species can be very robust and accumulate large subcanopy dunes of plant parts and eolian sand. Occasionally, shadscale is also associated with the other shrub species; it often occurs on mound interspaces. Torrey saltbush also occurs on mound interspaces, but rarely. We have seldom witnessed Torrey saltbush existing alone on a single mound, but greasewood often does. Inland saltgrass (*Distichlis stricta* [Torr.] Rydb.) is an associated plant that most often occurs at the lower edges of mounds and migrates onto the mound interspaces.

SOIL-SOLUTION CHEMISTRY

Saturation extract values are presented in table 2. These data indicate that the mounds are very saline, as saline or more saline than the unvegetated mound interspaces. The soil solution of dune bare spots and of the mound rooting zone of greasewood contains significantly ($P \leq 0.05$) greater levels of most measured species than occur in the soil solution from the other samples. The soil solution of dune interspaces immediately adjacent to the mounds of the rooting zone of allenrolfea and Torrey saltbush have similar values of electrical conductivity and levels of extracted ions. The soil solution of playa sediments beneath dunes has, in general, lower levels of soluble species than the other samples. Notable in most samples are the high levels of bromide, nitrate, lithium, and boron. The levels of boron measured would be toxic to many plants. When compared to the chemistry of seawater, one can see that the mounds are more saline (table 2).

DISCUSSION

Our working hypothesis postulated that the mounds were less saline than the unvegetated interspaces. Clearly, this hypothesis must be rejected, for mounds are as saline or more saline than interspace surfaces. However, it is possible that plants may recruit on the mound owing to a favorable seedbed, as compared to the denser and finer textured interspace sediments. Once established, these plants could pump water from the underlying water table, which is less saline than the mound soil solution (table 3). Greasewood and species of *Atriplex* are facultative phreatophytics (Franclet and LeHouerou 1971; Robertson 1983) and once established could be expected to function well even on the very saline mounds, because they obtain water from the underlying water table. However, we also reject this hypothesis because the calculated osmotic potential of the mound surface seedbed, based on the electrical conductivity of the saturation extract, was always greater than –2.0 MPa. This calculated value undoubtedly underestimates the true osmotic potential of the soil solution because soil moisture rarely if ever approaches saturation. Thus, the osmotic potential of the soil seedbed is too negative for seeds of greasewood (Romo and Haferkamp 1987) and allenrolfea (table 4) to germinate.

We propose a third alternative hypothesis that explains mound formation and plant-mound association and is supported by field evidence and the soil-solution data presented earlier. Mounds are cyclic in nature. Formation begins as seeds recruit on a favorable, low-osmotic-potential seedbed. Plants mature and begin to capture eolian sand, thereby building mounds. Geochemical cycling by plants leads to

Table 3—Chemistry of four wells located among allenrolfea mounds

Well	Electrical conductivity	Chloride	Nitrate	Sulfate	Sodium	Potassium
	dS/m			µg/mL		
A	26	7,560	1.1	1,890	436	4,430
B	36	10,150	5.5	2,050	906	6,110
C	19	5,770	6.4	327	308	3,510
D	27	7,510	3.8	4,070	489	4,070

Table 4—Percent germination of allenrolfea seeds in different osmotic solutions

Salt	Osmotic potential (MPa)					
	0	−0.2	−0.8	−1.6	−2.4	−3.0
	- - - - - - - - - - - - - Percent - - - - - - - - - - - - -					
NaCl	36	36	35	30	6	1
$Na_2SO_4.10H_2O$	51	39	30	0	0	0

increased soil salinity. Eventually, mounds become too saline for seed germination, the aged plants die, and the unprotected mounds blow away. Vasek and Lund (1980) have evoked a similar model to explain plant succession on playas in the Mojave desert.

Field evidence in support of this new hypothesis includes the observation that much recruitment occurs in washes and fresh eolian sediments. Analysis of these materials indicated they are far less saline than mature mounds, mound interspaces, or older materials underlying the freshly deposited sediment (table 5). The fact that all mounds examined were very saline (in our scenario, very old) suggests that large-scale recruitment of plants and the initiation of mound formation occurs rarely and may depend on environmentally optimal periods—unusually heavy rains or eolian movement. The conclusion that the mounds are aged is supported by the finding of significant differences in root zone soil-solution values among the different plants. This indicates that plants have existed in place for a sufficient time for differential geochemical recycling of salts to occur. Soil enrichment of salts through the decomposition of leaves and fruits of *Atriplex* has been reported (Roberts 1950; Sharma and Tongway 1973). Last, the surfaces of many barren mounds have exposed root material of former shrubs, presumably greasewood, which indicates that the mounds have become too saline to support plant growth and begun to erode.

REFERENCES

Billings, W. D. 1945. The plant association of the Carson Desert region, western Nevada. Butler University Botanical Studies. 8: 89-123.

Franclet, A.; LeHouerou, H. 1971. The *Atriplex* in Tunisia and North Africa. FA: SF/Tun 11, Tech. Rep. 7. Food and Agriculture Organization of United Nations. 271 p.

Gee, G. W.; Bauder, J. W. 1986. Particle-size analysis. In: Klute, A., ed. Methods of soil analysis. Part 1, No. 9 in Agronomy series. Madison, WI: American Society of Agronomy: 377-382.

John, M. K.; Chuah, H. H.; Neufeld, J. H. 1975. Application of improved azomethine-H methods to the determination of boron in soils and plants. Analytical Letters. 8: 559-568.

Mifflin, M. D.; Wheat, M. M. 1979. Pluvial lakes and estimated pluvial climates of Nevada. Univ. Nev. Bull. 94. Reno, NV: Nevada Bureau of Mines and Geology, Mackay School of Mines. 57 p.

Nelson, D. W.; Sommers, L. E. 1982. Total carbon, organic carbon, and organic matter. In: Page, A. L., ed. Methods of soil analysis. Part 2, No. 9 in Agronomy series. Madison, WI: American Society of Agronony: 539-580.

Roberts, E. C. 1950. Chemical effects of salt-tolerant shrubs on soils. International Congress of Soil Science. 4th Amsterdam. 1: 404-406.

Robertson, J. H. 1983. Greasewood (*Sarcobatus vermiculatus* [Hoop.] Torr.). Phytologic. 54: 309-324.

Romo, J. T.; Haferkamp, M. R. 1987. Effects of osmotic potential, potassium chloride, and sodium chloride on germination of greasewood (*Sarcobatus vermiculatus*). Great Basin Naturalist. 47: 110-116.

Russell, I. C. 1895. Present and extinct lakes of Nevada. National Geographic Magazine Monographs. 1: 101-132.

Sharma, M. L.; Tongway, D. J. 1973. Plant induced soil salinity patterns in two saltbush (*Atriplex* spp.) communities. Journal of Range Management. 26: 121-125.

Soil Survey Staff. 1984. Procedures for collecting soil samples and methods of analysis for soil survey. Soil Surv. Invest. Rep. 1. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 68 p.

Soil Survey Staff. 1990. Keys to soil taxonomy. Soil Manage. Support Serv. Tech. Monogr. 19. 4th ed. Blacksburg, VA: Virginia Polytechnic Institute. 422 p.

U.S. Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. Agric. Handb. 60. Washington, DC: U.S. Department of Agriculture. 160 p.

Vasek, F. C.; Lund, L. J. 1980. Soil characteristics associated with a primary plant succession on a Mojave desert dry lake. Ecology. 61: 1013-1018.

Weaver, R. M.; Syers, J. K.; Jackson, M. L. 1968. Determination of silica in citrate-bicarbonate-dithionite extracts of soils. Soil Science Society of America Proceedings. 32: 497-501.

Weiss, J. 1986. Handbook of ion chromatography. Sunnyvale, CA: Dionex Corporation. 244 p.

Table 5—Saturation extract chemistry of recent eolian material, its underlying eolian material, and recent fluvial sediments

Sample	Electrical conductivity	Chloride	Sulfate	Sodium	Potassium	Nitrate
	dS/m	- µg/mL -				
Recent eolian 1	1.2	145	131	241	40	0
Underlying	38	10,790	821	5,425	633	12
Recent eolian 2	3.2	558	155	548	46	0
Underlying	34	12,400	651	5,349	447	19
Recent eolian 3	1.4	220	145	284	38	0
Underlying	16	4,800	131	3,244	245	0
Recent fluvial 1	1.7	—	—	—	—	—

SAGEBRUSH COMMUNITIES ON CLAYEY SOILS OF NORTHEASTERN CALIFORNIA: A FRAGILE EQUILIBRIUM

Robert R. Blank
James D. Trent
James A. Young

ABSTRACT

Many western rangeland communities are in a fragile equilibrium as a consequence of deleterious soil properties and adverse climatic conditions. A combination of mismanagement, a series of dry years, and invasion by alien annuals can trigger a cascading set of events that eventually leads to a less productive site. Soils on the volcanic terrain of northeastern California, regions once occupied by Tertiary lakes, are very clayey with high shrink-swell. High-condition areas are occupied by a shrub-perennial grass mixture. The principal shrubs are Lahontan sagebrush (Artemisia arbuscula ssp. longicaulis [proposed taxon]) and basin big sagebrush (Artemisia tridentata ssp. tridentata). The presence of shrubs on these clayey soils has, over time, increased the site potential by capturing eolian dust. This veneer of coarse-textured material is a better seedbed than the clayey substratum, supports an extensive cryptogamic community, and limits the natural churning of the high shrink-swell clays. Past overgrazing has, in some instances, caused the veneer of eolian dust to erode, exposing the clay substratum. These sites now support a near monoculture of medusahead (Taeniatherum caput-medusae). If medusahead invades on high-condition sites, wildfires may occur, and, consequentially, wind erosion increases, the eolian veneer is thinned, and a permanent loss in site potential can occur. Rehabilitation of medusahead sites, before fires and critical erosional events, is hampered by a lack of suitable revegetation species, by inadequate seeding technologies suited to these clayey and surface cobbly soils, and possibly by the loss of soil mycorrhizal spore reservoirs by virtue of shrub subcanopy deflation.

INTRODUCTION

Soil, the climate it is exposed to, and the flora and fauna it supports are inextricably linked (Jenny 1941). Through a feedback mechanism, organisms engender physical and chemical attributes to soil. This feedback mechanism is clear when one follows biotic succession beginning on young soils (Dickson and Crocker 1953; Mirsky 1966; Syers and

others 1970). Pioneer species enrich the soil with nitrogen and organic matter leading to the establishment of midseral species. The midseral species continue to build up available reserves of soil nutrients and begin the long process of layering or horizonation in soils. Finally, climax species render a near steady state and soil horizons further differentiate.

Biotic succession can be disturbed by many events. In ecosystems subjected to prolonged dry seasons, wildfires can set back succession (Wright and Bailey 1982). Such disturbances, in general, do not directly impact soil development or permanently reduce the potential of the soil; biotic succession is capable of reaching a similar endpoint as before the disturbance. However, some ecosystem disturbances have the potential to irreparably change not only the vegetation patterns but shift the equilibrium of soil development. Anthropogenic increases of atmospheric carbon dioxide is a current example that has received worldwide attention in regard to its effect on plants (Smith and others 1987). The introduction of alien plant species into the landscape can also disturb the plant-soil ecosystem. In the basin and range, the invasion of cheatgrass (*Bromus tectorum*) is leading to ecosystem impoverishment through increased fire frequency (Billings, in press; Young and Evans 1978). The new quasi-equilibrium established by cheatgrass monoculture, with consequential loss of a shrub component and biotic diversity, radically alters geochemical cycling as compared to precheatgrass vegetation and over time reduces the soil potential. Another example of ecosystem change through alien invasion is the introduction of iceplant (*Mesembryanthemum crystallinum*) in Egypt (El-Ghareeb 1991). This plant has increased soil salinity, through plant recycling, to the point that native annuals are unable to germinate in the high-osmotic-potential surface soils.

On the volcanic terrain of northeastern California and northwestern Nevada, large acreages of clayey soils occur. Over a period of thousands of years, the native sagebrush-grass vegetation has captured eolian material to form a coarse-textured veneer overlying the much more clayey substratum. This eolian veneer has increased the potential of the highly churning clayey soils. However, in the last 30 years the alien invader medusahead (*Taeniatherum caput-medusae*) has gained a foothold in many regions of California (Young and Evans 1970). This paper presents evidence that medusahead invasion in combination with past overgrazing has caused the eolian veneer to deflate and voices our concerns about potential permanent soil degradation over large acreages of clayey soils in northeastern California and northwestern Nevada.

MATERIALS AND METHODS

The study area is in Lassen County, CA, approximately 30 km east of Susanville and about 5 km north of Honey Lake. This is the southern extension of the Modoc Plateau, a region of northeastern California where voluminous extrusive volcanic deposition occurred during the Pliocene and Pleistocene (Lydon and others 1960). Precipitation averages about 25 cm per year.

Pedons were field-described and sampled using established procedures (Soil Survey Staff 1984, 1990). Collected soil was immediately air-dried, then lightly crushed to pass a 2-mm sieve. All subsequent analyses were performed on this material. Soil moisture release curves were determined using a pressure membrane apparatus (Richards and Fireman 1943). Organic carbon was determined by the Walkley-Black method (Nelson and Sommers 1982). The ammonium acetate method was used to determine cation exchange capacity (Soil Survey Staff 1984). The method of Harris (1971) was used to gauge aggregate stability. Particle size determination used the pipette method (Gee and Bauder 1986). Vesicular-arbuscular mycorrhizal (VAM) root colonization was determined using the staining procedure of Phillips and Hayman (1970) and the gridline intersect method described by Kormanik and McGraw (1982). Mycorrhizal spore and nematode counts in soils were qualified by the sucrose density centrifugation method (Allen and others 1979).

GEOLOGY AND ORIGIN OF CLAYS

During the Tertiary period, extrusive volcanic flows periodically dammed water outflows, which resulted in the formation of large lakes. Contemporaneous with lake formation, volcanic ejecta from the rising Cascades contributed large volumes of tephra that rained into the lakes. Diagenesis or alteration of this lake-laid tephra formed 2 to 1 expanding lattice aluminosilicate clay minerals (group name of smectite). These particular smectites possess high levels of shrink-swell and unusual water retentive properties (table 1).

Soils dominantly smectitic in composition, like those formed in these Tertiary clays, are self-churning Vertisols. The high shrink-swell of this clayey material has, over a period of thousands of years, rafted underlying cobbles and boulders to the soil surface, which presents problems for ecosystem reconstruction of degraded areas.

THE PLANT COMMUNITIES

Our field surveys indicate that three major plant communities occur on these clayey soils (table 2). The Lahontan sagebrush community is dominant on uplands and is the most biologically diverse community. Shrub subcanopies contain much eolian dust, which supports an extensive cryptogamic community. The eolian veneer extends to the interspaces and varies in depth from 0 to 10 cm. Shrub interspaces, which make up approximately 50 percent of the community, are largely devoid of vegetation, but pedestals formed by Sandberg bluegrass (*Poa sandbergii*) are common. Vesicular surface crusts, which cover much of the interspaces, are coated with a thin cryptogamic community, which we suspect is dominantly cyanobacteria.

Table 1—Soil moisture release values for the medusahead soil[1]

Horizon	Matric potential (MPa)				
	0.005	0.2	0.3	1.0	1.5
	Percent moisture by weight				
A	55	39	36	32	29
BA	58	39	36	31	28
Bss1	53	39	36	31	29
Bss2	49	39	35	30	28
Bw	47	35	33	30	28

[1]See table 3 for description of medusahead soil.

The basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*) community occurs in broad lowlands that receive run-in moisture, on small upland depressions, and on uplands near breaks of individual volcanic flows. These plants are much larger than Lahontan sagebrush, but possibly due to breaking of lower branches by grazing animals, the subcanopy dune is not well expressed. In this community there are fewer shrubs than in the Lahontan sagebrush, and the interspaces among shrubs are much larger. We estimate that the interspaces make up 60 to 70 percent of the community. Perhaps because of the severe drought of the last 5 years, the interspaces contain little vegetation, visually less than the Lahontan sagebrush community. As far as we can tell, this community lacks an eolian veneer.

The medusahead community presently occurs in small isolated patches of very clayey soils. Given the history of sheep grazing in this area, it is possible that some of the initial medusahead invasion was fostered by overutilization. These sites consist of a surface mulch of undecomposed medusahead. The extremely high silica content of medusahead makes it unpalatable to livestock and resistent to decomposition (Swenson and others 1964). Litter can accumulate and therefore carry wildfires in a community that, under pristine conditions, was likely fire-resistant. Few shrubs occur in medusahead-invested rangelands. The medusahead community usually borders with the Lahontan sagebrush community.

PLANT-SOIL RELATIONSHIPS

Corresponding soil profiles and soil properties associated with plant communities are presented in table 3. The Lahontan sagebrush soil consists of a coarse-textured, eolian-deposited surface. In the interspaces, the eolian veneer is compact and vesicular, but beneath shrub canopies the eolian material is less dense. Evidence of more recent eolian- and fluvial-deposited sand is common. Occasionally one witnesses clay "blowouts" where it appears water has accumulated in depressions. Subsequent expansion of the underlying clay pushed through the eolian veneer to form a small mound. Underlying the eolian veneer is a well-structured, very clayey, Bt horizon with thick clay films coating the prism faces. Beneath the Bt horizon is a horizon of calcium carbonate and silica accumulation. These compounds have caused soil cementation to produce an incipient duripan. This soil would be classified as a Typic Durargid. The horizonation of this soil indicates thousands of years of stability from shrink-swell, which

Table 2—Plant communities on clayey soils

Lahontan sagebrush (A. arbuscula ssp. longicaulis)[1]	Basin big sagebrush (A. tridentata ssp. tridentata)	Medusahead (Taeniatherum asperum)
Sandberg bluegrass (Poa sandbergii)	Green rabbitbrush (Chrysothamnus viscidiflorus)	Cheatgrass (Bromus tectorum)
Bluebunch wheatgrass (Agropyron spicatum)	Littleleaf horsebrush (Tetradymia glabrata)	Japanese brome (Bromus japonicus)
Idaho fescue (Festuca idahoensis)	Spiny hopsage (Grayia spinosa)	Columbia needlegrass (Stipa columbiana)
Columbia needlegrass (Stipa columbiana)	Cheatgrass (Bromus tectorum)	Bluebunch wheatgrass (Agropyron spicatum)
Astragalus malacus	Squirreltail (Elymus hystrix)	Squirreltail (Elymus hystrix)
Lomatian piperi		
Wild onion (Allium anserinum)		

[1]Proposed taxon by Winward and others.

Table 3—Pedon descriptions of soils associated with basin big sagebrush, Lahontan sagebrush, and medusahead

Horizon	Depth	Munsell color (dry)	Soil structure		Sand	Silt	Clay	Organic carbon	Cation exchange capacity	IA[1]
			Primary	Secondary						
	cm						-Percent-		cmol(+)/kg	
Lahontan sagebrush										
E	0-5	10YR 6/1	medium platy	—	59	36	5	0.52	5	10
Bt1	5-15	10YR 5/2	medium prismatic	medium blocky	32	23	46	.44	30	21
Bt2	15-36	7.5YR 4/2	coarse prismatic	medium blocky	24	18	58	.42	46	25
Bt3	36-66	10YR 4/4	coarse prismatic	medium blocky	26	23	50	.37	52	31
Bkq	66-91	10YR 5.5/3	platy	—	21	40	39	.31	53	22
Basin big sagebrush										
A	0-5	10YR 5/1.5	very fine blocky	—	31	33	37	.72	32	23
BA	5-20	10YR 4.5/1.5	medium prismatic	medium blocky	25	25	51	.51	33	21
Bss	20-46	7.5YR 5/2	coarse prismatic	wedges & blocky	23	24	53	.35	49	20
Bw1	46-86	10YR 5/3	coarse prismatic	medium blocky	24	29	48	.35	52	12
Bw2	86-122	10YR 5/3	coarse prismatic	medium blocky	24	29	48	.29	51	20
Medusahead										
A	0-5	10YR 3.5/2.5	cloddy & blocky	very fine blocky	8	36	56	1.06	36	17
BA	5-15	10YR 4.5/2	cloddy	fine blocky	8	33	58	.37	36	16
Bss1	15-27	10YR 5/2	wedges & platy	medium blocky	7	34	59	.30	33	12
Bss2	27-65	10YR 5/2	coarse prismatic	coarse blocky	7	34	59	.31	34	10
Bw	65-88	10YR 5/3	coarse blocky	medium blocky	7	33	60	.31	37	7

[1]IA or index of aggregation is a measure of wet aggregate stability. Values approaching 100 indicate high stability; value near 0 indicate weak stability. For comparative purposes, surface horizons in native prairies of South Dakota have IA values greater than 90.

would obscure horizon formation. Given the high natural shrink-swell of these soils, it is apparent that some factors do not allow the natural churning process in these soils to obscure horizon formation. We suspect the eolian veneer, the cryptogamic community it supports, and the shrub subcanopy intercept most precipitation before it reaches the clayey substratum, thus delimiting the natural churning processes.

The basin big sagebrush soil consists of a thin A horizon that has a very strong and very fine granular to blocky structure, which, if felt dry, appears to be a sand. The A horizon grades into a transitional horizon then to a blocky- and wedge-structured Bss horizon. The presence of wedge-shaped structural units, pressure faces on structural units, as well as the indistinctness of soil horizons all indicate extensive shrink-swell activity. The soil would be classified as a Vertisol.

The medusahead soil has a cloddy to massive surface structure that breaks down to strong fine granular to blocky, similar to the basin big sagebrush soil. The soil

surface is strewn with basalt cobbles, and in this regard it is similar to the Lahontan sagebrush soil. In places, the surface is punctuated by large cracks, some nearly 5 cm wide, which extend over 1 m into the soil. These are larger cracks than were seen at the other sites. Undecomposed plant parts of medusahead are intermixed with the surface layer, which may explain the elevated organic carbon levels in comparison to the other sites. Underlying the surface horizon is a cloddy-structured transitional horizon that is more compact and less structured than seen in the other soils. Beneath this transitional layer occurs a thick wedge- and prismatic-structured layer with many slickensides on wedge faces. This layer indicates extensive shrink-swell activity, characteristic of vertisols, and it is much more expressed than in the basin big sagebrush soil. Below the slickenside horizons is a blocky-structured horizon with lo- cal accumulations of calcium carbonate and gypsum. A cal- cium carbonate and silica cemented horizon, similar to the Lahontan sagebrush soil, was not seen in any of several soil pits examined in medusahead-infested areas.

SOIL MICROBIOLOGY

Although the role of mycorrhizal fungi in the revegetation of mine spoils (Danielson 1985) by native plant species has been established, less attention has been paid to the role they play in revegetation of heavily disturbed rangelands. Hypothetically, plant-VAM relations can occur along a con- tinuum ranging from obligate mycotrophy to nonmycotrophy (Allen and Allen 1990). Such relationships can influence the competitive outcome between plant species depending on the presence or absence of mycorrhizal soil inoculum.

It has been demonstrated that pioneering annual plants can be nonmycorrhizal (Allen and Allen 1980; Miller 1979; Reeves and others 1979). A possible ramification of soil disturbance and colonization by medusahead could be a decrease in soil mycorrhizal inoculum potential. Thus, recruitment of native perennial grasses and shrubs, which are mycorrhizal, into medusahead-infested areas would be hampered by the lack of inoculum. Our laboratory work indicates that medusahead is in fact mycorrhizal (15 to 20 percent colonization at anthesis), which suggests that

mycorrhizal inoculum potential is present in these soils. Although VAM fungal spores are present in the medusa- head soils, they occur in lower numbers than in the sage- brush dune soils (table 4). In addition, there appears to be a shift in the species composition in the spores. A greater proportion of the total spores in the medusahead soils are *Glomus deserticola* (27 to 65 percent of total spores), while fewer occur in the sagebrush dune soil (2 to 19 percent of total). This change in VAM species composition may be a result of shifts in plant species (medusahead soils tend to be a monoculture, while sagebrush soils have higher plant diversity), or as a result of edaphic changes. Perhaps *G. deserticola*, which is a small spore, is better adapted to the shrink-swell environment that occurs on the vertisol clays. In general, shrub subcanopies appear to be rich repositories of mycorrhizal spores. If mismanagement and medusahead invasion destroy shrub subcanopies, one would expect a shift in VAM species composition and that mycorrhizal spore den- sities would decrease. These are important considerations in understanding the resiliency of this ecosystem.

A FRAGILE EQUILIBRIUM

These clayey soils, because of water-retentive properties and the arid climate, are in a fragile equilibrium. Invasion by the alien annual grass medusahead has shifted this equilibrium from a shrub-perennial grass-dominated sys- tem to an annual grass-dominated system. Our scenario for ecosystem impoverishment on these clayey soils is as follows: Once medusahead establishes on degraded sites, genetic selection will enable it to invade high-condition sites (Young and Evans 1970). The high silica content of medusa- head will allow plant litter to accumulate. Accumulated medusahead litter will enable catastrophic wildfires to occur in an ecosystem that, under pristine conditions, was fire-resistant. The loss of shrubs and the cryptogamic com- munity will destabilize the eolian veneer. If revegetation efforts are not timely, erosion will expose the clayey subsoil. Subsequent precipitation on these clayey subsoils will be- gin soil churning; an argid with distinct profile differentia- tion will convert to a vertisol. We are reasonably sure that this conversion will result in a near-permanent loss of site

Table 4—Enumeration of mycorrhizal spores and nematodes by microsite

| Collection microsite | Spores | | | | Nematodes |
	Glomus deserticola	Other mycorrhizae	Dead mycorrhizae	Total spores	
	------------------------- Numbers/25 g soil -------------------------				
Lahontan sagebrush interdune	1	43	29	44	0
Lahontan sagebrush dune	5	291	288	296	11
Basin big sagebrush interdune	8	97	39	105	1
Basin big sagebrush dune	75	327	97	402	9
Medusahead A	77	41	32	118	0
Medusahead B	31	85	23	116	0
Medusahead C	45	70	23	115	1

potential as compared to similar soils with an eolian veneer. The high clay content of the clayey surface soil and its water-retentive properties will result in a very poor seedbed for native plant species. Degraded medusahead sites will only increase their potential through soil stabilization that can occur only after the reintroduction of shrubs, formation of cryptogamic communities, and the slow aggradation of eolian sand.

The preliminary conclusions in this paper will be subject to future revision based on field studies presently under way. However, we believe this treatment is warranted, given the potential for permanent site degradation.

RESEARCH NEEDS

We need to delineate soil, plant, and microbial factors that allow successful invasion of medusahead on clayey soils. Armed with this knowledge we may be able to initiate control strategies that are compatible with present environmental regulations. Plant genotypes need to be developed that can compete with medusahead, such as bunchgrasses that will reduce the risk of wildfires. Furthermore, research on the role of soil microorganisms such as mycorrhizal fungi that might enhance the establishment of native grasses and shrubs should be pursued. In addition, we need to determine management strategies that promote growth and stabilization of cryptogamic communities that are very important in the stabilization of the soil seedbed.

REFERENCES

Allen, M. F.; Moore, T. S.; Christensen, M. 1979. Growth of vesicular-arbuscular mycorrhizal and non-mycorrhizal *Bouteloua gracilis* in a defined medium. Mycologia. 71: 666-669.

Allen, E. B.; Allen, M. F. 1980. Natural re-establishment of vesicular-arbuscular mycorrhizae following stripmine reclamation in Wyoming. Journal of Applied Ecology. 17: 139-147.

Allen, E. B.; Allen, M. F. 1990. The mediation of competition by mycorrhizae in successional and patchy environments. In: Perspectives on plant competition. New York: Academic Press: 367-389.

Billings, W. D. [In press]. *Bromus tectorum*, a biotic cause of ecosystem impoverishment in the Great Basin. In: Woodwell, G. M., ed. The earth in transition: patterns and processes of biotic impoverishment. New York: Cambridge University Press.

Danielson, R. M. 1985. Mycorrhizae and reclamation of stressed terrestrial environments. In: Tate, R. L.; Klein, D. A., eds. Soil reclamation processes, microbiological analyses and application. New York: Marcel Dekker: 173-194.

Dickson, B. A.; Crocker, R. L. 1953. A chronosequence of soils and vegetation near Mt. Shasta, California. I. Definition of the ecosystem investigated and features of the plant succession. Journal of Soil Science. 4: 123-154.

El-Ghareeb, R. 1991. Vegetation and soil changes induced by *Mesembryanthemum crystallinum* L. in a Mediterranean desert ecosystem. Journal of Arid Environments. 20: 321-330.

Gee, G. W.; Bauder, J. W. 1986. Particle-size analysis. In: Klute, A., ed. Methods of soils analysis. Part 1. No. 9 in Agronomy series. Madison, WI: American Society of Agronomy: 377-382.

Harris, S. 1971. Index of structure: evaluation of a modified method of determining aggregate stability. Geoderma. 6: 155-162.

Jenny, H. 1941. Factors of soil formations. New York: McGraw-Hill. 281 p.

Kormanik, P. P.; McGraw, A. C. 1982. Quantification of vesicular-arbuscular mycorrhizae in plant roots. In: Schenk, N. C., ed. Methods and principles of mycorrhizal research. St. Paul, MN: The American Phylopathological Society: 37-45.

Lydon, P. A.; Gay, T. E.; Jennings, C. W. 1960. Geologic map of California: Westwood sheet. Sacramento, CA: Division of Mines, California Department of Natural Resources.

Miller, R. M. 1979. Some occurrences of vesicular-arbuscular mycorrhizae in natural and disturbed ecosystems of the Red Desert. Canadian Journal of Botany. 57: 619-623.

Mirsky, A., ed. 1966. Soil development and ecological succession in a deglaciated area of Muir inlet, southeast Alaska. Report 20. Columbus, OH: Institute for Polar Studies Research Foundation.

Nelson, D. W.; Sommers, L. E. 1982. Total carbon, organic carbon, and organic matter. In: Page, A. L., ed. Methods of soil analysis. Part 2. No. 9 in Agronomy series. Madison, WI: American Society of Agronomy: 539-580.

Phillips, J. M.; Hayman, D. S. 1970. Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. Transactions of the British Mycological Society. 55: 158-161.

Reeves, F. B.; Wagner, D.; Moorman, T.; Kiel, J. 1979. The role of endomycorrhizae in revegetation practices in the semi-arid west. I. A comparison of incidence of mycorrhizae in severely disturbed versus natural environments. American Journal of Botany. 66: 6-13.

Richards, L. A.; Fireman, M. 1943. Pressure plate apparatus for measuring moisture sorption and transmission by soils. Soil Science. 56: 395-404.

Smith, S. D.; Strain, B. R.; Sharkey, T. D. 1987. Effects of CO_2 enrichment on four Great Basin grasses. Functional Ecology. 1: 139-143.

Soil Survey Staff. 1984. Procedures for collecting soil samples and methods of analysis for soil survey. Soil Survey Investigation Rep. 1. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service.

Soil Survey Staff. 1990. Keys to soil taxonomy. Soil Management Support Services Tech. Monogr. 19. 4th ed. Blacksburg, VA: Virginia Polytechnical Institute. 422 p.

Swenson, C. F.; Le Tourneau, D.; Erickson, L. C. 1964. Silica in medusahead. Weeds. 12: 16-18.

Syers, J. K.; Adams, J. A.; Walker, T. W. 1970. Accumulation of organic matter in a chronosequence of soils developed on wind-blown sand in New Zealand. Journal of Soil Science. 21: 146-153.

Wright, H. A.; Bailey, A. W. 1982. Fire ecology: United States and southern Canada. New York: John Wiley & Sons. 501 p.

Young, J. A.; Evans, R. A. 1970. Invasion of medusahead into the Great Basin. Weed Science. 18: 89-97.

Young, J. A.; Evans, R. A. 1978. Population dynamics after wildfires in sagebrush grasslands. Journal of Range Management. 31: 283-289.

INSECT GALLS AND CHEMICAL COMPOSITION OF LEAVES OF WHITE RUBBER RABBITBRUSH ON RIPARIAN AND DRY SITES

D. J. Weber
G. Wilson Fernandes

ABSTRACT

Previous studies by Fernandes revealed that a higher number of insect galls were present on white rubber rabbitbrush (Chrysothamnus nauseosus *ssp.* hololeucus) *on dry hillside sites as compared to riparian sites. Chemical analyses of the hydrocarbon fraction from leaves of* C. nauseosus *ssp.* hololeucus *from the same sites were made by gas chromatography and mass spectrometry. The total hydrocarbon fraction was higher on the dry hillside sites, but the number of individual compounds was greater in the hydrocarbon fraction from the riparian sites. Of particular interest was the presence of a pregnane type of compound, which was present at higher concentration in the leaves of the plants on the dry sites.*

INTRODUCTION

Rubber rabbitbrush (*Chrysothamnus nauseosus*) has a number of subspecies that are adapted to a wide range of environmental conditions (Anderson 1986). Although it is a semiarid shrub, rubber rabbitbrush normally responds with increased biomass on riparian sites (Weber and others 1985).

Insect galls caused by gall midges, tephritid flies, and lepidopterans are common on subspecies of rubber rabbitbrush (Fernandes and Price 1992). McArthur and others (1979) used several types of the tephritid galls as indicators of different subspecies. Fernandes and Price (1988, 1991) investigated five hypotheses to account for the variation in galling species number on plants. Their results supported the hypothesis that the gall-forming habit was an adaptation to harsh or stressful environments. Fernandes and Price (1992) determined that the number of insect galls on *C. nauseosus* ssp. *hololeucus* was higher on the dry hillside as compared to the riparian sites. Furthermore, survivorship was significantly higher on plants living in harsh environments. The purpose of this investigation was to determine if chemical differences existed in the hydrocarbons of leaves of *C. nauseosus* ssp. *hololeucus* that were grown on dry and riparian sites and whether these chemical differences could be related to the formation of galls by insects.

MATERIALS AND METHODS

Leaves of *C. nauseosus* ssp. *hololeucus* were collected from the same sites analyzed for insect gall populations by Fernandes (1991) on the San Francisco Peaks in Arizona. Paired dry hillside and riparian sites were used. Samples of leaves from 30 plants on the hillside and 30 plants in the riparian area were collected and analyzed.

Hydrocarbon Extraction

Each collection of leaves was ground in a steel mortar and pestle with liquid nitrogen (Hegerhorst and others 1987). The samples were stored in a freezer at -20 °C until extraction. Three grams of ground leaf material was weighed and placed in a Kimwipe folded tissue and stapled with one staple. The plant material in folded Kimwipe tissue was placed in a vial.

Three mL of hexane containing a stable isotope internal standard (^{13}C naphthalene) was added to the vial with the sample and sealed with a lid. The vials and sample were heated in a microwave oven for 30 seconds and the extract removed by decanting (Bhat and others 1989). The extraction process was repeated four times. The extracts were combined and concentrated at room temperature by evaporation of part of the hexane.

Gas Chromatography Analysis

The extracts were separated into compounds on a bonded capillary column in a Hewlett Packard (HP) 5890 gas chromatograph. The temperature program for the gas chromatograph was: injector port 250 °C, detector 300 °C, column programmed from 40 °C to 280 °C at a rate of 5 °C per min. Automatic sample injection transferred 1 µL of the extract to the column.

Capillary Gas Chromatography-Mass Spectrometry

One µL of extract was automatically injected into the HP 5995. A capillary column was programmed from 40 °C to 280 °C at 5 °C per min. The mass spectrometer detector was set at 300 °C and the injector port at 250 °C. The mass spectra from the individual peaks were stored in the HP1000 computer and compared to the mass spectra library of 90,000 spectra. The area under the peaks was used as

a compared value of concentrations of the compounds. The peak area was not converted to absolute concentrations. The internal standard was used to normalize the data for comparison purposes. Statistical analysis was made with Statview, a Macintosh statistical program (Statview II 1989).

RESULTS

The compounds found at the dry site and at the riparian site are shown in tables 1 and 2. Only compounds greater than 1 percent of the total area are listed in the table. The total number of compounds detected was greater for the

Table 1—Compounds detected in the hydrocarbon fraction of *Chrysothamnus nauseosus* ssp. *hololeucus* from dry hillside sites. Only compounds present in greater than 1 percent are listed

Peaks	Name	Probability	Ret. time	Peak area
1	beta Pinene	95	9.7	4303733
2	beta Phellandrene	96	10.8	5703355
3	Deutro naphthalene (internal standard)	96	13.9	
4	Acetic acid, octyl ester	76	14.2	10088701
5	Geranyl acetate	83	16.8	15130153
6			17.1	
7	alpha Cubebene	95	17.3	30770693
8	Bicyclo dec-1-en,2 isopropyl-5-methyl-9-methylene	88	17.4	7345591
9	trans Caryophyllene	96	18.8	7060077
10			19.0	
11	Geranyl propionate	85	19.9	10847883
12	Benzene, 1-(1,5-dimehtyl-4-hexenyl)-4-methyl	95	19.1	16932446
13	beta Cubebene	95	20.8	165261807
14	delta Cadinene	78	20.9	67701539
15	Calarene	55	21.0	
16	epi-Bicyclosesquiphellandrene	60	21.1	73198790
17			21.3	
18			21.4	
19	Patchulane	(¹)	21.5	6424715
20			21.6	
21			21.7	
22	Pentadecane (C15)	(¹)	22.0	40734821
23			22.2	
24	Heptacosane (C17)	97	22.7	12543505
25	Cyclopropane, 1.1 dimethyl 2 (2 methyl 3 buten 2 yl)	60	22.5	8310325
26	Cyclopentalclpyran 4 carboxylic acid 7 methyl ester	(¹)	23.3	75075924
27			24.8	
28	Benzene, tetraethyl	(¹)	25.2	28807706
29	Indole-3-acetic acid, methyl ester	(¹)	26.6	135300620
30	Cyclopenta pyran-4-carboxylic acid 7-methyl, meth ester	(¹)	26.8	21752387
31	Nonadecane (C19)	99	27.5	24549773
32			29.0	
33			29.8	
34	Henecosane (C21)	89	30.1	17445823
35	Tricosane (C23)	99	30.3	12256749
36			30.6	
37	Cyclodecadien 1 one, 10 (1 methylethenyl)	(¹)	31.1	15200124
38			31.3	
39	3 Butan-2-one, 4-phenyl	51	31.4	1406753486
40	Ergost-14-ene (pregnane)	(¹)	31.8	556174528
41			32.1	
42			32.8	
43			33.1	
44	Heptacosane (C27)	99	33.3	41324397
45			33.7	
46			34.3	
47	Tricosane (C30)	99	34.7	179869357
48			35.1	
49	Tritriacontane (C33)	96	35.3	8075040
50			36.7	
51	Hexatriacontane (C36)	94	37.4	149788830
				3154732878

¹Probability less than 50 percent.

moist riparian site than for the dry hillside site. However, the total peak area of the compounds was greater for the dry hillside sites as compared to the more moist riparian sites.

The peak areas of the compounds separated by gas chromatography and analyzed by mass spectrometry were converted to a bar graph and are shown in figure 1 for the hillside and riparian sites. Of particular interest was the presence of two large peaks. The two peaks from the dry hillside site represent 62 percent of the hydrocarbon fraction; the two peaks for the moist riparian site represent 19 percent of the hydrocarbon fraction. One of the peaks has a pregnane (sterol-like) type of structure (Deepak and others 1989). The amount of the pregnane type was higher at the

Table 2—Compounds detected in the hydrocarbon fraction of *Chrysothamnus nauseosus* ssp. *hololeucus* from moist riparian sites. Only compounds present in excess of 1 percent are listed

Peaks	Name	Probability	Ret. time	Peak area
1				
2				
3	Deutro naphthalene (internal standard)	90	13.7	
4				
5	Geranyl acetate	79	16.7	29130674
6	1 Decene (C10)	(¹)	17.1	4385002
7				
8				
9	trans Caryophyllene	96	18.8	11014749
10	Naphthalene, octahydro-7-methyl-4-meth	84	19.0	2709231
11				
12	Benzene, 1-(1,5-dimethyl-4-hexenyl)-4-methyl	92	19.1	4803714
13	beta Cubebene	82	20.8	78716616
14	delta Cadinene	78	20.9	12528338
15	Calarene	55	21.0	15701631
16	epi-Bicyclosesquiphellandrene	60	21.1	12742903
17	Tricyclo heptane dimethyl methyl pentenyl	(¹)	21.3	1030135
18	Octadecane, 2 methyl	79	21.4	3228384
19	Patchulane	(¹)	21.2	2352254
20	Tetradecane (C14)	86	21.6	5740257
21	Phenanthridinone	(¹)	21.7	2188934
22	Pentadecane (C15)	87	22.0	3804675
23	Imidazole ethanamine	(¹)	22.2	6519749
24	Heptacosane (C17)	97	22.7	9238282
25				
26				
27	Octadecane (C18)	89	24.8	18438095
28				
29	Indole-3-acetic acid hydrazide	(¹)	22.9	3559139
30	Cyclopenta pyran-4-carboxylic acid 7-methyl, meth ester	(¹)	23.0	39578846
31	Nonadecane (C19)	90	27.5	15811632
32	Eicosane (C20)	89	29.0	2654930
33	Benzene-1,3 dichloro 2 ethyl	(¹)	23.3	9992654
34	Henecosane (C21)	89	24.1	15300141
35	Tricosane (C23)	99	25.3	25391713
36	Benzene, 1,3 bis dimethylethyl	(¹)	26.1	5298713
37	Cyclododecatriene, trimethyl	(¹)	27.6	21210671
38	delta Guaiene	(¹)	28.7	4550446
39	3 Butan-2-one, 4-phenyl	51	30.2	710966398
40	Ergost-14-ene (pregnane)	(¹)	31.3	329709978
41	Tetracosane (C24)	96	32.1	6315938
42	Pentacosane (C25)	96	32.8	14901091
43	Hexacosane (C26)	91	33.1	6430687
44	Heptacosane (C27)	99	33.6	30344871
45	Octacosane (C28)	96	33.7	7238478
46	Nonacosane (C29)	90	34.3	169140523
47	Tricosane (C30)	99	34.8	8321242
48	Hentriacontane (C31)	95	35.1	43121322
49	Tritriacontane (C33)	96	35.7	49773727
50	Pentatriacontane (C35)	91	36.1	2759274
51	Hexatriacontane (C36)	94	37.7	5897002
				1752543039

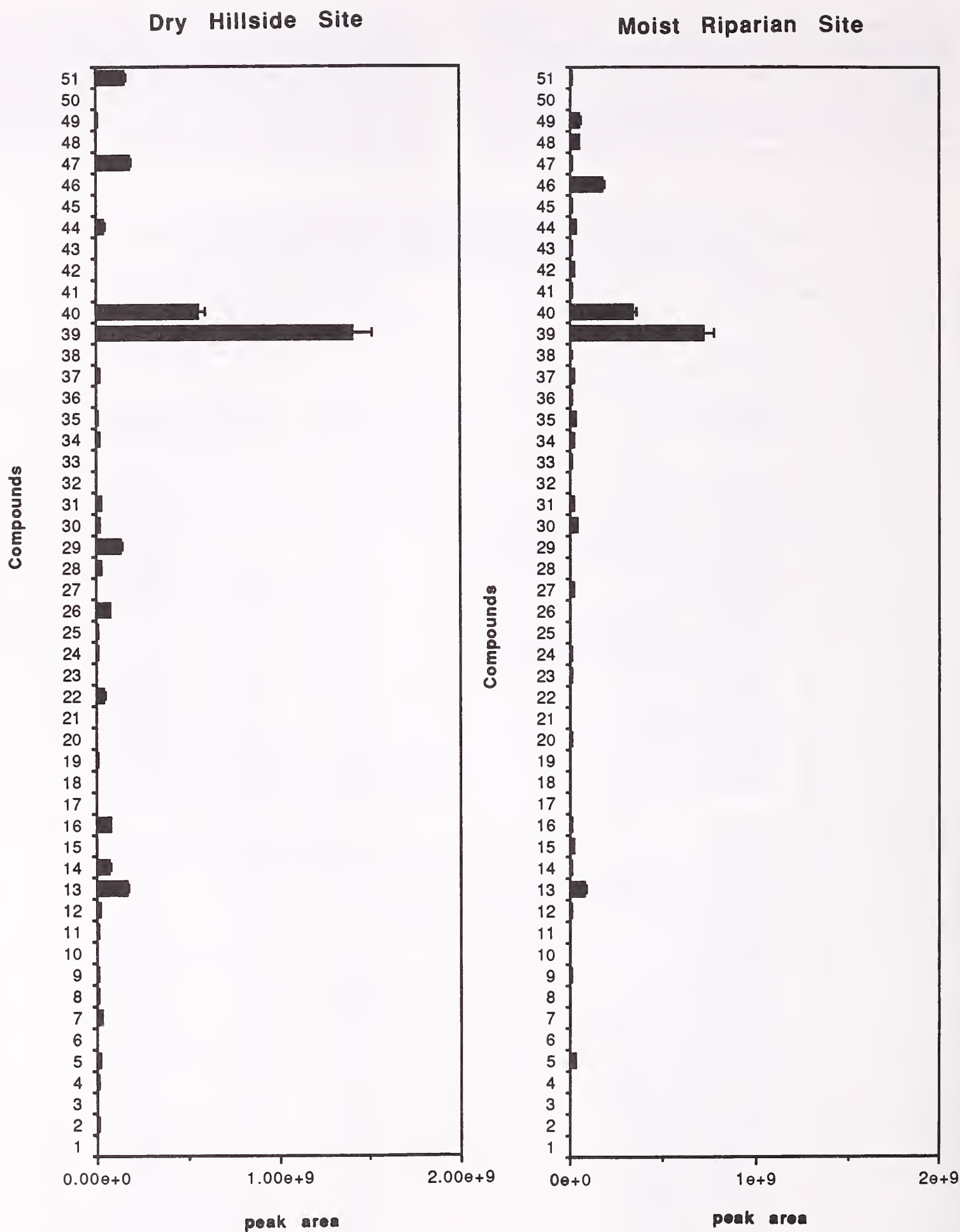¹Probability less than 50 percent.

Figure 1—Comparison of the peak area of compounds found in the hydrocarbon fraction of *Chrysothamnus nauseosus* ssp. *hololeucus* from dry hillside sites and moist riparian sites. The numbers refer to the compounds listed in tables 1 and 2.

dry hillside as compared to the moist riparian site. There are over 45 reported pregnanes (Deepak and others 1989). The exact chemical structure of the pregnane is still being determined.

DISCUSSION

The increased number of compounds produced at the riparian sites is probably a reflection of more-diverse metabolic activity. These compounds could be antigalling compounds, but no assays with galling insects were conducted. On the other hand, it was surprising that the amount of hydrocarbons was greater at the dry site. This could be due to the increased production of leaf-coating materials to reduce transpiration in response to stress. At the same time, the stressed plant produced less variety but higher amounts of the individual compounds. However, the increase in amount of the two major peaks for the dry site accounts for a large amount of the increase. The pregnanes are in the same group as animal hormones and could be a factor in the attraction of the galling insects. However, no direct insect attraction assays have been made.

The basis for increased insect galling at the drier sites could be the absence of an antifeedant in the leaves of the plant or the increased amount of pregnane type of compound that may be attracting galling insects.

ACKNOWLEDGMENTS

We wish to acknowledge the technical help of Ken Hellewell, R. B. Bhat, and Dale Hegerhorst in sample preparation.

REFERENCES

Anderson, L. C. 1986. An overview of the genus *Chrysothamnus* (Asteraceae). In: McArthur, E. D.; Welch, B. L., compilers. Proceedings—symposium on the biology of *Artemisia* and *Chrysothamnus*; 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 29-45.

Bhat, R. B.; Hegerhorst, D. J.; Weber, D. J.; Smith, B. N.; McArthur, E. D.; Chrominski, A. 1989. Microwave method for rapid extraction of rubber and resin from plant tissue. Phyton. 49: 23-26.

Deepak, D.; Khare, A.; Maheshwari, P. K. 1989. Plant pregnanes. Phytochemistry. 28: 3255-3263.

Fernandes, G. W.; Price, P. W. 1992. The adaptive significance of insect gall distributions: survivorship of species in xeric and mesic habitats. Oecologia (in press).

Fernandes, G. W.; Price, P. W. 1988. Biogeographical gradients in galling species richness: tests of hypotheses. Oecologia. 76: 161-167.

Fernandes, G. W.; Price, P. W. 1991. Comparison of tropical and temperate galling species richness: the roles of environmental harshness and plant nutrient status. In: Price, P. W.; Lewinsohn, T. M.; Fernandes, G. W.; Benson, W. W., eds. Plant-animal interactions: evolutionary ecology in tropical and temperate regions. New York: John Wiley & Sons.

Fernandes, G. 1991. Insect gall populations on *Chrysothamnus nauseosus* ssp. *hololeucus* on dry and riparian sites. 15 p. Unpublished report.

Hegerhorst, D. J.; Weber, D. J.; Bhat, R. B.; Davis, T. D.; Sanderson, S. C.; McArthur, E. D. 1987. Seasonal changes in rubber and resin in *Chrysothamnus nauseosus* ssp. *hololeucus* and ssp. *turbinatus*. Biomass. 15: 133-142.

McArthur, E. Durant; Tiernan, Charles F.; Welch, Bruce L. 1979. Subspecies specificity of gall forms on *Chrysothamnus nauseosus*. Great Basin Naturalist. 39: 81-87.

Statview II. 1989. Statistical methods for the Macintosh. Calabasas, CA: Brainpower, Inc. 180 p.

Weber, D. J.; Davis, T. D.; McArthur, E. D.; Sankhla, N. 1985. *Chrysothamnus nauseosus* (rubber rabbitbrush): multiple-use shrub of the desert. Desert Plants. 7: 180, 208-210.

BITTERBRUSH SEED DORMANCY— A DISCUSSION

D. T. Booth

ABSTRACT

Bitterbrush seed dormancy may be due to direct interference with cell metabolism (inhibitor theory), or to an oxygen deficient, nondormant embryo (hypoxic theory). Three questions are posed for discussion of these theories. Questions one and two rely upon published literature for possible answers. Question three is being addressed by testing for glycolytic inhibition by bitterbrush seed coat chemicals. Results to date indicate that bitterbrush seed-coat chemicals will inhibit glycolysis.

INTRODUCTION

There are two theories to explain seed dormancy in bitterbrush. The first is that dormancy is due to direct chemical inhibition. No specific mechanism has been described for chemical inhibition or for its reversal, but we will assume some type of direct interference with cell metabolism. The second theory, which I will refer to as the hypoxia theory, is that seed coat-imposed hypoxia (low oxygen) prevents germination. This indirect effect was suggested by Young and Evans (1976) and was the first plausible description of a mechanism that might explain germination and dormancy in bitterbrush seeds. I will briefly review the two theories and offer some question-and-answer discussion.

DORMANCY THEORIES

Chemical inhibitors have long been suspected as factors in seed dormancy (Mayer and Poljakoff-Mayber 1989: 93). Nord (1965) believed bitterbrush had a water-soluble inhibitor located in the seed coat. He reported that more than 80 percent germination could be obtained within 4 days when the embryo was removed from the seed coat and cultured on moist filter paper (Nord 1956, 1965; Nord and Van Atta 1960). Later Dreyer and Trousdale (1978) identified the triterpenes cucurbitacins D(1) and I(2), isolated from ethyl acetate extracts of seeds, as water-soluble constituents of bitterbrush seeds. They noted the seeds also contained "large amounts" of phenolics. Several cucurbitacins, including I, have pronounced inhibitor activity and are reported to be gibberellin antagonists (Guba and Sen 1973). However, Dreyer and Trousdale were unable to show that either of the bitterbrush cucurbitacins inhibited germination. Yet they did show that the mother liquor containing the two triterpenes was inhibitory.

Young and Evan's (1976) description of a possible process leading to germination of dormant bitterbrush seeds is based on reports by the French seed physiologist Comé (Comé and Tissaoui 1972). Comé has noted that the only oxygen available to embryos of imbibed seeds is dissolved in the water absorbed by the seed, and that the concentration of dissolved oxygen is a function of temperature. Seed coats containing phenolic compounds are thought to use part of the dissolved oxygen when the phenolics oxidize. As the temperature increases, embryo and chemical oxygen demands also increase, but dissolved oxygen decreases. Therefore, nondormant embryos of seeds imbibed at 20 °C are likely to be oxygen deficient. Comé and Tissaoui (1972) reported that less than 1 percent oxygen is sufficient for apple seed embryos to germinate if they are held at 4 °C. If they are held at 20 °C, at least 5 percent oxygen is required.

How well do the ideas of Comé and Tissaoui (1972) apply to bitterbrush? Young and Evans (1976) compared bitterbrush stratification times and temperatures relative to subsequent germination of seeds incubated at 15 °C. Stratification at −4 °C had no effect on seed dormancy. As treatment temperatures increased above 0 °C, the stratification time required for optimum germination decreased (table 1). Since seed metabolism is temperature related, this is natural. But Young and Evans (1976) also found that germination dropped sharply as the stratification temperature increased above 5 °C. Note that water that is 50 percent oxygen saturated loses one fifth of its oxygen as the temperature increases from 0 to 10 °C (table 1). So, it is possible that the oxygen concentration at 5 °C is nearing a critical point for bitterbrush, and that at warmer temperatures hypoxia interferes with germination.

Table 1—Bitterbrush germination related to stratification time and temperature.[1] The concentration of dissolved oxygen in water at 50 percent of saturation[2] is presented for reference

Stratification		Dissolved	Mean
Temp.	Time	oxygen	germination
°C	Days	mg/L	Percent
10	1	570	10
8	10	600	30
5	14	640	>70
2	21	700	>70
0	28	720	>70

[1]Bitterbrush data are from Young and Evans (1976).
[2]Dissolved oxygen data are from Sedgwick (1978).

EVALUATING THE THEORIES

Question One—Can the theory of direct chemical inhibition account for seed germination under cool-moist conditions? Canadian investigators have demonstrated that endogenous *p*-coumaric acid will inhibit germination of maple seeds (*Acer saccharum*). And they have measured a substantial decrease in concentration of the acid over the course of 60 days of moist chilling (fig. 1). The decrease was attributed to catabolism of the inhibitor. Other authors have also noted the ability of seeds to metabolize potential inhibitors (Khan 1977: 33; Mayer and Poljakoff-Mayber 1989: 182). Therefore, it is possible that chemical inhibitors in bitterbrush seeds are catabolized during stratification. Young and Evans (1976) found that seeds with the stratification requirements satisfied became very susceptible to pathogens. Is this because an inhibitor was broken down during stratification? We have no evidence that an inhibitor is catabolized, and no evidence to the contrary. So, catabolism of chemical inhibitors is one possible reason for bitterbrush germination after stratification.

Question Two—If an inhibitor is carried into the bitterbrush embryo as moisture is absorbed, why isn't germination inhibited when the imbibed embryo is extracted from the seed coat? Membranes surrounding the embryo may allow an inhibitor to pass through the membrane to the embryo, but not in the reverse direction. Thus, extracting the embryo from the seed and incubating it on moist filter paper would leach out a previously contained inhibitor.

For years, the upper seed of cocklebur (*Xanthium pennsylvanicum*) was considered to be a classic example of coat-imposed dormancy due to limited gas exchange. This hypothesis was challenged by Wareing and coworkers, who found that water-soluble inhibitors in cocklebur, and also in sycamore maple (*Acer pseudoplatanus*), do not leach from the embryo if the testa is intact (fig. 2; Bewley and Black
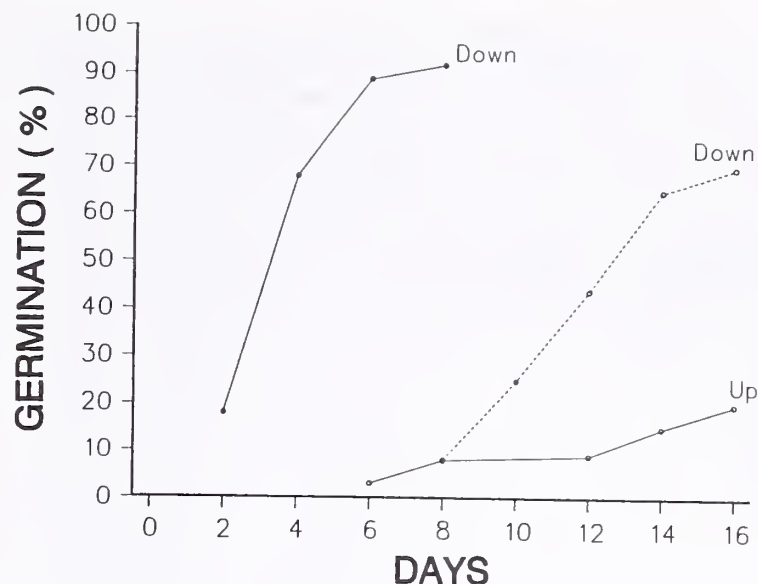
Figure 2—Data presented by Webb and Wareing (1972) showing the effect of leaching on the germination of sycamore maple. Seeds with the testa torn were placed on moist filter paper so that the hole in the testa was down and in contact with free liquid and leaching of the embryo could occur, or up so that leaching of the embryo did not occur. The broken lines represent the percentage germination of "up" seeds that were placed "down" at day 8.
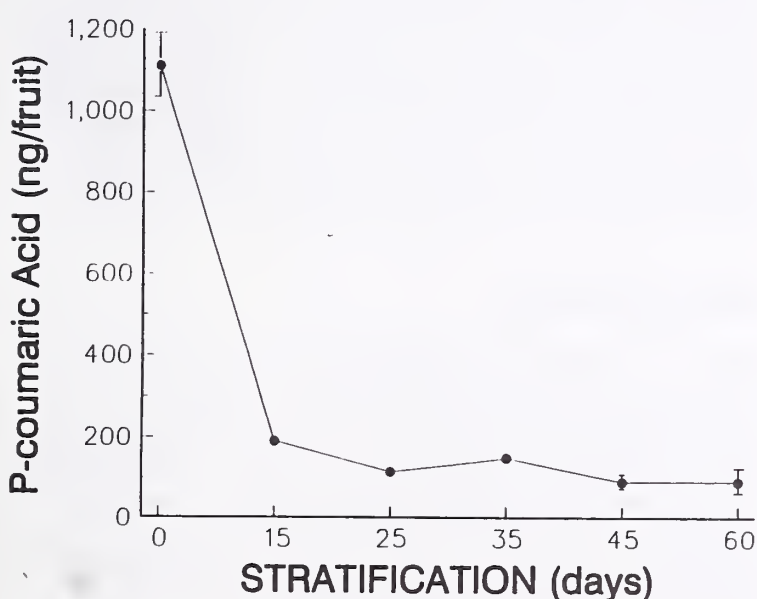

Figure 1—Data presented by Enu-Kwesi and Dumbroff (1980) showing the effect of stratification at 5 °C on the level of *p*-coumaric acid in the pericarp of sugar maple. Vertical bars show the mean ± one standard error where it exceeds the size of the symbol.

1982: 96). We have no evidence that the bitterbrush seed testa influences the movement of an inhibitor, nor do we have evidence that it does not.

Question Three—This question addresses the hypoxic theory. If bitterbrush does not germinate because its nondormant embryo is hypoxic, what prevents the seed from fermenting? Or, to ask the question another way, does glycolysis occur in imbibed, viable, nongerminating bitterbrush seeds? Glycolysis is a process of the cell cytoplasm and under aerobic conditions produces pyruvate for the Krebs Cycle. If an organism is hypoxic, glycolysis produces ethanol and lactic acid, which can build to toxic levels in seeds. Imbibed, viable, nongerminating bitterbrush seeds do not appear to ferment. Is glycolysis inhibited?

A TEST OF GLYCOLYTIC INHIBITION

To learn whether bitterbrush seed-coat chemicals could inhibit glycolysis, I measured ethanol formation in anaerobically incubated yeast-sucrose mixtures with and without seed-coat extracts. Seventy-two grams of bitterbrush seed were soaked for a day, then washed with distilled water to obtain about a liter of filtrate. This was concentrated to 60 mL by evaporation, then divided into three solutions: (A) the original extract, (B) the original extract minus an ethyl acetate fraction, and (C) the ethyl acetate fraction, which was redissolved in water and the ethyl acetate removed by evaporation. On the basis of Dryer and Trousdale's (1978) work, I believe solution A contained all water-soluble compounds in the seed coat, solution B the phenolic compounds, and solution C the cucurbitacins.

Each solution was tested at full strength and at 50 percent of full strength. These were compared to a distilled water check. Each treatment was replicated five times. Incubations were carried out in 15 mL Gilson Respirometer flasks using 3.5 mL of the test solution with 0.4 g of dry baker's yeast. One mL of a 20 percent (w/w) sucrose solution buffered to pH 4.8 with 0.02 M potassium phosphate was added to the sidearm of each flask. Loaded flasks were flushed with carbon dioxide, weighed to 0.01 mg, and placed in an agitating water bath at 30 °C for 15 minutes to equilibrate. The contents of the sidearm were dumped into the reaction vessel and the flasks incubated for 3 hours with agitation. The flasks were removed from the water bath, dried, weighed, and the contents filtered through #4 Whatman filter paper and stored at 2 °C. Ethanol was measured by gas chromatography. A flame ionization detector was used with a 183- by 0.21-cm Porapak N column. Column temperature was 150 °C, injector and detector temperatures were 190 °C. Helium was the carrier gas.

Regression analysis of the relationship between weight loss and ethanol concentration was used to check results. Outliers were removed from the data and treatment means and the 95 percent confidence interval calculated. Treatment means were then compared to determine if bitterbrush extracts reduced ethanol production.

RESULTS AND DISCUSSION

All extracts, except solution C (ethyl acetate fraction) at 50 percent of full strength (C_{50}), inhibited ethanol production and reduced weight loss from the solutions (fig. 3). The ethanol concentration averaged across all solutions with extract, except C_{50}, was 3 nL of ethanol/uL of solution. The distilled water check had 28 nL of ethanol/uL of solution. Ethanol in C_{50} was 22–, and in C full strength, less than 1 nL of ethanol/uL of solution. Weight loss from the solutions was less precise than measurements of ethanol, but the data are sufficient to corroborate the ethanol data. The low concentrations of ethanol and the low weight loss from solutions containing bitterbrush seed-coat extract imply that seed-coat chemicals inhibited glycolysis in yeast. Since glycolysis is a basic process of respiring organisms, the answer to question three is that the chemicals of the bitterbrush seed coat have the potential to inhibit glycolysis within bitterbrush embryo cells.

There may be an evolutionary advantage for dormant seeds to have glycolytic inhibitors. If glycolysis proceeds, it does so at the expense of the food stored in the seed. If the seed is not in a germination mode, the energy and products derived from glycolysis may not be available for later growth. If the seed embryo is oxygen deficient, the food is diverted to toxic products. Therefore, a dormant (nongerminating) seed has a greater probability for germination and postgermination survival with glycolysis inhibited during dormancy.

CONCLUSIONS

The role of chemical inhibitors in seed dormancy is one of the most researched aspects of seed physiology, yet the evidence remains ambiguous. Bewley and Black (1982: 205) have extensively reviewed the case for chemical inhibition and have aptly stated:
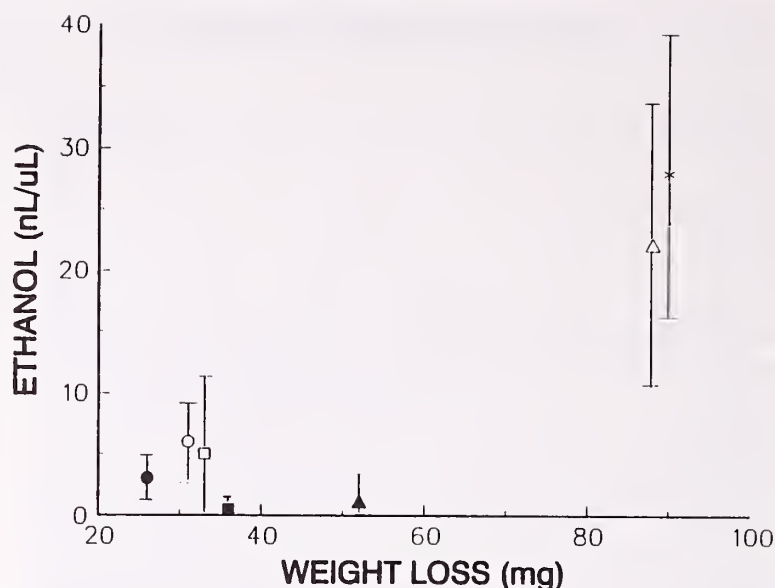

Figure 3—Effect of bitterbrush seed-coat extracts on weight loss from the solution, and on ethanol production of yeast-sucrose solution incubated anaerobically at 30 °C. Filled symbols represent full-strength solutions, open symbols represent solutions at 50 percent of full strength. Circles = A, all water soluble compounds; squares = B, phenolics; triangles = C, cucurbitacins; and x = distilled water. The mean ± the 95 percent confidence interval is indicated by the vertical bars.

If we attribute dormancy to the action of these inhibitors, we must then inquire as to how they operate: but ... there is very little information available to help us deal with this question.

The weakness of the hypoxic theory is that it fails to explain why nondormant embryos of viable, nongerminating seeds do not ferment. The weakness of the inhibitor theory is that it fails to give a specific mechanism for inhibition. The inhibitor theory is simply a large "black box" titled "metabolic inhibition." Since bitterbrush seed-coat extract inhibited glycolysis in the yeast-sucrose solutions, we have evidence that a smaller "black box" titled "glycolytic inhibition" might be a useful consideration in studies of seed dormancy. Whether testing for glycolytic inhibition is one step in a diversion, or one step toward the truth about bitterbrush seed dormancy, remains to be seen.

REFERENCES

Bewley, J. D.; Black, M. 1982. Physiology and biochemistry of seeds. Vol. 2. New York: Springer-Verlag. 375 p.

Comé, D.; Tissaoui, T. 1972. Interrelated effects of imbibition, temperature, and oxygen on seed germination. In: Heydecker, W., ed. Seed ecology. University Park, PA: Pennsylvania State University Press: 157-168.

Dreyer, D. L.; Trousdale, E. K. 1978. Cucurbitacins in *Purshia tridentata*. Phytochemistry. 17: 325-326.

Enu-Kwesi, L.; Dumbroff, E. B. 1980. Changes in phenolic inhibitors in seeds of *Acer saccharum*. Journal of Experimental Botany. 31(121): 425-436.

Guba, J.; Sen, S. P. 1973. Antigibberellins of the Cucurbitaceae. Nature New Biology. 244: 223-224.

Khan, A. A. 1977. Seed dormancy: changing concepts and theories. In: Khan, A. A., ed. The physiology and biochemistry of seed dormancy and germination. Amsterdam: North-Holland Biomedical Press: 29-50.

Mayer, A. M.; Poljakoff-Mayber, A. 1989. The germination of seeds. Elmsford, NY: Pergamon Press. 270 p.

Nord, E. C. 1956. Quick testing bitterbrush seeds. Journal of Range Management. 9: 193-194.

Nord, E. C. 1965. Autecology of bitterbrush in California. Ecological Monographs. 35(3): 307-334.

Nord, E. C.; Van Atta, G. R. 1960. Saponin—a seed germination inhibitor. Forest Science. 6(4): 350-353.

Sedgwick, S. D. 1978. Trout farming handbook. New York: Scholium International. 169 p.

Webb, D. P.; Wareing, P. F. 1972. Seed dormancy in *Acer pseudoplatanus* L.: the role of the covering structures. Journal of Experimental Botany. 23(76): 813-829.

Young, J. A.; Evans, R. A. 1976. Stratification of bitterbrush seeds. Journal of Range Management. 29(5): 421-425.

2u5

PRESCRIBED FIRE EFFECTS ON A BITTERBRUSH-MOUNTAIN BIG SAGEBRUSH-BLUEBUNCH WHEATGRASS COMMUNITY

W. Wyatt Fraas
Carl L. Wambolt
Michael R. Frisina

ABSTRACT

Effects of burning 8 years earlier were measured in a bit-terbrush (Purshia tridentata Pursh)-mountain big sage-brush (Artemisia tridentata Nutt. ssp. vaseyana [Rydb.] Beetle)-bluebunch wheatgrass (Agropyron spicatum Pursh) community. Bitterbrush density did not differ between burned and unburned sites, while bitterbrush canopy cover, flower production, and seed production were less on the burned site. Mountain big sagebrush canopy cover and density were less on the burned site. Total herbaceous canopy cover did not differ between sites.

INTRODUCTION

Fire has often been used to reduce shrub density for the benefit of livestock grazing, with intentions of improving access for livestock, reducing competition for more palat-able species, and increasing production of desired forage species (Daubenmire 1970). However, shrub reduction does not always increase herbaceous production (Blaisdell 1953; Daubenmire 1975; Kuntz 1982; Mangan and Autenrieth 1985; McNeal 1984; Peek and others 1979; Sturges and Nelson 1986). In addition, management ap-proaches for one species or habitat may be inappropriate for another (Rotenberry and Wiens 1978). For example, shrubs provide a major, if not critical, winter big-game food source in the Rocky Mountains (Hamlin and Mackie 1989; Kufeld 1973; Kufeld and others 1973). Our study site on a southwestern Montana big-game winter range and cattle grazing allotment represented typical areas where this type of conflict between management for livestock or wildlife could occur.

We examined a bitterbrush (*Purshia tridentata* Pursh)-mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* [Rydb.] Beetle)-bluebunch wheatgrass (*Agropy-ron spicatum* Pursh) site in 1990 that had been partially prescribed burned eight seasons earlier. Bitterbrush was of particular interest on the site due to its importance as

big-game forage, variable response to burning (Martin and Driver 1983; Rice 1983), and relatively infrequent occur-rence here on the northeastern edge of its range (McArthur and others 1983).

Our specific objectives on this burn site were to deter-mine: (1) the percentage of bitterbrush sprouting in the prescribed burn area, (2) the ability of normally browsed bitterbrush plants to grow and reproduce after fire, and (3) plant community differences between burned and un-burned portions of an otherwise homogenous site.

STUDY SITE

The study area is located on the south flank of Steep Mountain, 8 km (5 mi) northwest of Butte, MT, at an eleva-tion of 2,010 m (6,600 ft). Precipitation on the site averages 400 to 450 mm (16 to 18 inches) per year (Ross and Hunter 1976). Precipitation at the nearest weather station (Silver Bow County Airport, 15 km southeast of Steep Mountain, elevation 1,700 m) averages 250 to 350 mm (10 to 14 inches) per year with 49 percent received between April and July. Precipitation in the year of the burn was 12 percent above average and 2 percent below average for the next 9 years. It was 4 percent below normal for the 12-month period pre-ceding this study (NOAA 1990). Soils are shallow cryochrepts with decomposing granite parent material. The plant com-munity is a bitterbrush-mountain big sagebrush-bluebunch wheatgrass association intermediate to the big sagebrush/ bluebunch wheatgrass and bitterbrush/bluebunch wheat-grass habitat types of Mueggler and Stewart (1980). Bit-terbrush plants exhibited a decumbent growth form with occasional layering.

The study area is part of a cattle-grazing allotment car-rying 125 cattle for 1 to 2 months each summer in a four-pasture rest-rotation system on the Butte Ranger District of the Deerlodge National Forest. The area is also winter range for mule deer (*Odocoelius hemionus* ssp. *hemionus* Raphinesque) and elk (*Cervus elaphus* ssp. *nelsoni* Bailey). Prior to burning, the site was estimated to have 20 percent canopy cover of mountain big sagebrush and bitterbrush. The Forest Service considered this to be undesirable, and a prescribed burn was planned to "kill sagebrush and en-hance grass and forb production for livestock and wildlife" (USDA 1981). Bitterbrush was to be left unburned due to its perceived high forage value to the big game. The site was rested from livestock use in 1981 to increase fuel loads and was burned on November 3, 1981. Weather conditions

at ignition were 37 percent relative humidity, air temperature of 11 °C (52 °F), and 17-29 m/sec (3-5 mi/h) south wind. Soil moisture was not recorded. The pasture was rested from livestock use until September 15 of the following year.

SAMPLING METHODS

Two study sites of 15 by 12 m (50 by 40 ft) were paired on areas of nearly identical slope, aspect, and parent material. The two sites were located approximately 6 m (20 ft) on both sides of the apparent burn line on slopes of 20 to 24 percent with south aspect. Plant canopy cover was measured along five, 15-m (50-ft) transect lines in each plot, placed perpendicular to the slope, and at 3-m (10-ft) intervals down the slope. Grass and forb cover were estimated by using a 2- by 5-dm (7.9- by 19.6-inch) quadrat and six canopy cover classes after Daubenmire (1959), with 10 quadrats per line. Plant frequency was determined from the number of quadrats containing each species. Shrub canopy was measured by the line intercept method (Canfield 1941). Live and dead shrub cover were recorded, with cover discontinuities greater than 8 cm (3.1 inches) recorded as changes in cover. Density of shrub species was measured in belt transects 2 m (6.5 ft) wide centered on the five transect lines. Bitterbrush plant volumes were estimated from measurements of live canopy thickness (maximum minus minimum height of live canopy), length of major axis, length of minor axis perpendicular to the major axis, and calculation of ellipsoid volume. Plant community parameters were measured in September 1990 after nearly all annual growth had occurred.

Ten bitterbrush plants rooted within 1 m of the transect lines were randomly selected on each plot. Four branches were randomly chosen on each plant and were marked with numbered metal tags. On each branch, age and length of each stem segment, number of flowers and leaders, length of leaders, and number of seeds produced were measured. Flowers were counted in early July and seeds were counted in early August. Leader length (current annual growth) and number of leaders were measured in early September of 1990. Measurements were compared only for twig segments 3 years old or less, as little bud activity occurred on older stems.

Bitterbrush plant ages were determined by examining growth rings from stem segments (Lonner 1972) cut from all plants in 1- by 12-m belt transects on either side of the study plots.

Plant community differences between the burned and unburned plots were compared with nonparametric statistical tests due to unequal variances and small sample sizes. These tests use ranking to compare samples and use medians rather than means. Therefore, results from these tests are presented with medians. A Student's t-test was used to compare bitterbrush production of the two sites. Tests were made using the hypergeometric probability, Mann-Whitney, and t-Grouped programs of the MSUSTAT statistical program (Lund 1991).

CANOPY COVER

Bitterbrush and mountain big sagebrush canopy cover were greater ($P < 0.01$) in the unburned plot (fig. 1). Bitterbrush grows slowly from seed, but can respond quickly
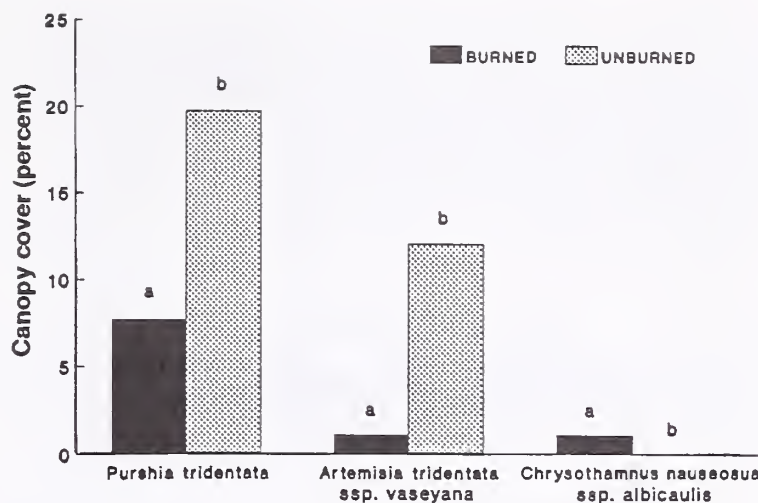

Figure 1—Median canopy cover of shrubs on burned and unburned sites. Pairs of bars with different letters are significantly different ($P < 0.01$).

to burning and topping by sprouting from root crowns and layering points (Blaisdell and Mueggler 1956; Jones 1983). However, while per-stem leader production has occasionally been higher on drastically treated plants, total plant and site production has decreased due to loss of total plant volume (Blaisdell 1953; Nord 1965; Murray 1983). Murray (1983) reported that more than 30 years could be required to regain prefire production levels. Mountain big sagebrush rarely sprouts after fire (Blaisdell 1953; Pechanec and others 1954), although it can vigorously reestablish from seed (Hironaka and others 1983). Apparently little sprouting or seedling reestablishment occurred on the burned area. Idaho fescue (*Festuca idahoensis* Elmer) canopy cover and frequency (fig. 2) were also higher on the unburned site, but the difference was not significant ($P > 0.20$), due to its variable distribution on the site. Long-term damage of Idaho fescue is common following fire (Blaisdell 1953; Hironaka and others 1983; Mangan and Autenrieth 1985; Nimir and Payne 1978; Pickford 1932). Sometimes 30 or more years are required for Idaho fescue to recover (Harniss and Murray 1973).

Bluebunch wheatgrass, total grass, and total forb canopy cover were similar ($P > 0.10$) on the burned and unburned sites (fig. 3). Reports of bluebunch wheatgrass response to fire have been mixed, ranging from short-term (1-3 years) and long-term (4-30 years) decreases (Blaisdell 1953; Daubenmire 1975), to short-term increases (Uresk and others 1975), to no change (Kuntz 1982; Mangan and Autenrieth 1985; Peek and others 1979; Sturges and Nelson 1986). Differences in habitat type, season and intensity of burn, and weather/soil conditions apparently contribute to the range of results. Total grass cover responds with similar variation (Daubenmire 1970).

SHRUB DENSITY

Bitterbrush density was not significantly different ($P > 0.30$) between the two plots (fig. 4), indicating a strong sprouting response, high seedling success, or both. Stem samples from the burn area showed that 50 percent of the sampled stems were younger than the burn (7 or 8 years old). These could have originated either as new seedlings or as sprouts, as old skeletons were not evident. Bunting

and others (1985) reported that the decumbent growth form is likely to sprout following fires, although sprouting frequencies of bitterbrush in mountain big sagebrush habitat types were found to be lower than for other habitat types in Idaho and Montana, averaging 29 percent, compared with at least 50 percent on this site.
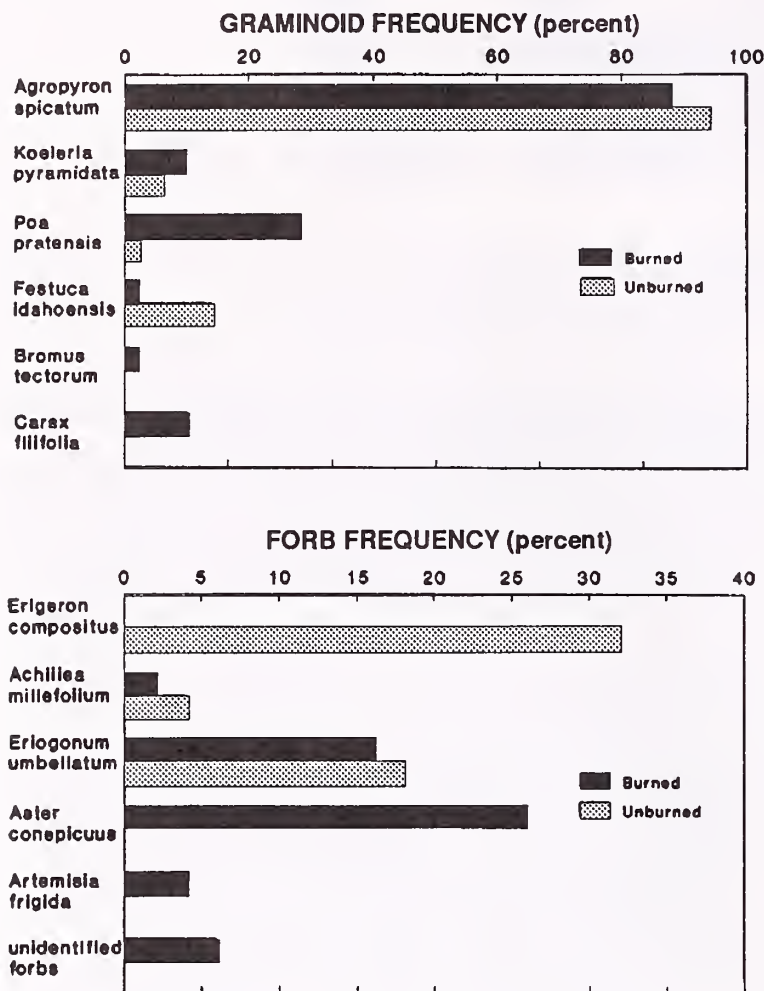

Figure 2—Frequency of occurrence of graminoids and forbs on burned and unburned sites (n = 50).
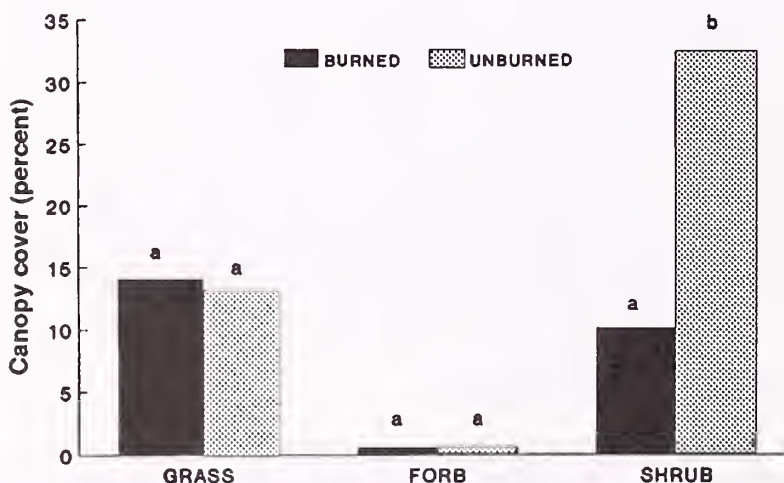
Mountain big sagebrush density decreased ($P < 0.01$) in the burn area (fig. 4), indicating a high mortality and lack of seedling establishment after burning, which others have also reported (Blaisdell 1953; Pechanec and others 1954). The more frequent occurrence of rubber rabbitbrush (*Chrysothamnus nauseosus* (Pallas) Britt. ssp. *albicaulis* (Nutt.) Hall & Clem.) in the burned area (figs. 1 and 4) concurs with many previous reports (Blaisdell 1953; Chadwick and Dalke 1965; Countryman and Cornelius 1957).

BITTERBRUSH GROWTH AND REPRODUCTION

Live bitterbrush volume (table 1) in the burned area was 16 percent of the volume in the unburned area ($P < 0.01$). This represents a large decrease in browse available to wintering ungulates, a condition which is likely to persist. Monsen and Shaw (1983) observed that newly sprouted bitterbrush would require at least 5 years to recover if browsed, while Murray (1983) found that bitterbrush production was still below unburned sites 30 years after burning. Klebenow (1985) noted that mule deer avoided large burned areas on Nevada winter range until bitterbrush and other shrubs had recovered, which often required 15 years. Other animals may also be affected. Sage grouse (*Centrocercus urophaseanus* Bonaparte) are considered to be obligates of sagebrush shrubland (Martin and Pyrah 1971). Rotenberry and Wiens (1978) reported many fewer sage and Brewer's sparrows (*Amphispiza belli* Cassin and *Spizella breweri* Cassin) in burned than in unburned sagebrush stands.

Total and average leader length of bitterbrush (table 1) were similar on the two sites, indicating similar growth rates for plants on both sites. Lengths of live twigs (3 or fewer years old) were also similar, indicating that the combination of growth and per-branch browsing pressure had been the same for the past 3 years for both sites.

Bitterbrush in the burn area produced fewer flowers and seeds than unburned plants ($P < 0.01$) (table 1). Bunting and others (1985) observed a similar condition in burned stands in Idaho and stated that bitterbrush sprouts require
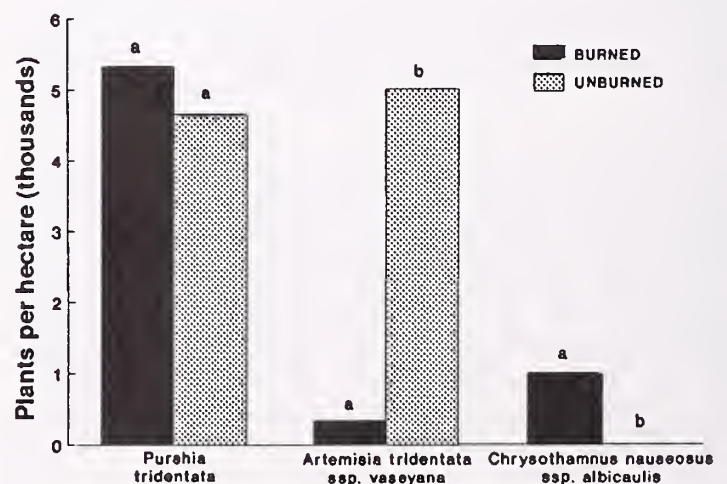

Figure 3—Median canopy cover of grasses, forbs, and shrubs on burned and unburned sites. Pairs of bars with different letters are significantly different ($P < 0.10$).

Figure 4—Median density of shrubs on burned and unburned sites. Pairs of bars with different letters are significantly different ($P < 0.10$).

Table 1—Mean bitterbrush reproductive and growth characteristics on prescribed-burned and unburned sites. Pairs of means followed by different letters are significantly different (P < 0.10)

Characteristics	Burned	Unburned	LSD[1]
Reproductive			
Flower production per branch	1.4[a]	31.2[b]	17.6
Seed production per branch	0.2[a]	11.0[b]	8.8
Growth			
Twig length per branch (mm)	880[a]	980[a]	210
Average leader length (mm)	30[a]	35[a]	8.8
Total leader length per branch (mm)	970[a]	1,230[a]	430
Average live plant volume (m³)	0.24[a]	1.86[b]	0.72

[1]Least significant difference for determining a difference at P < 0.10.

about 10 years to reach reproductive maturity and contribute as a seed source. This could delay the spread or recovery of bitterbrush on sites where little sprouting occurs or where few unburned plants remain to supply seeds.

Average age of bitterbrush plants in the unburned stand was 25.6 years, with a range of 13 to 33 years (n = 15). This is at the low end of average stand ages reported for Montana (Guenther 1989; Lonner 1972).

COMMUNITY COMPOSITION

More plant species occurred in the burned site than the unburned site (fig. 2). However, total grass and total forb cover was similar between the two sites (fig. 3), indicating that species composition had shifted following the fire. Rubber rabbitbrush, threadleaf sedge (*Carex filifolia* Nutt.), cheatgrass (*Bromus tectorum* L.), creeping aster (*Aster conspicuus* Lindl.), fringed sagewort (*Artemisia frigida* Willd.), and several unidentifiable forbs were found in only the burned plot. Fernleaf fleabane (*Erigeron compositus* Pursh) was found in only the unburned plot. Others have reported a similar increase in species diversity (Johnson and Strang 1983), similar individual species tolerances to fire (Blaisdell 1953; Harniss and Murray 1973; Nimir and Payne 1978; Pechanec and others 1954; Ralphs and others 1975), and community composition changes (McNeal 1984).

CONCLUSIONS

Burning shrubland in southwestern Montana may not result in intended increases in grass and forb production, but may result in unplanned shifts in plant community composition. These shifts may be detrimental on big-game winter range when they result in depressed shrub production or if critical plant species are eliminated. Shrub recovery may take decades after burning and care must be taken to ensure both an adequate quality and quantity of food sources on critical habitat areas.

Total plant community response and all resource values should be considered in relation to management goals when planning for prescribed fire in shrublands. In addition, land managers should include long-term site monitoring in their plans to determine if their management actions result in the desired effects.

REFERENCES

Blaisdell, J. P. 1953. Ecological effects of planned burning sagebrush-grass range on the Upper Snake River Plains. Tech. Bull. 1075. Washington, DC: U.S. Department of Agriculture. 34 p.

Blaisdell, J. P.; Mueggler, W. F. 1956. Sprouting of bitterbrush following burning or top removal. Ecology. 37(2): 365-370.

Bunting, S. C.; Neuenschwander, L. F.; Gruell, G. E. 1985. Fire ecology of antelope bitterbrush in the northern Rocky Mountains. In: Lotan, James E.; Brown, James K., compilers. Fire's effects on wildlife habitat—symposium proceedings; 1984 March 21; Missoula, MT. Gen. Tech. Rep. INT-186. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 48-57.

Canfield, R. H. 1941. Application of the line intercept method in sampling range vegetation. Journal of Forestry. 39: 388-394.

Chadwick, H. W.; Dalke, P. D. 1965. Plant succession on dune sands in Fremont Co., Idaho. Ecology. 46(6): 765-780.

Countryman, C. M.; Cornelius, D. R. 1957. Some effects of fire on a perennial range type. Journal of Range Management. 10: 39-41.

Daubenmire, R. 1975. Plant succession on abandoned fields and fire influences in a steppe area in southeastern Washington. Northwest Science. 49: 36-48.

Daubenmire, R. F. 1959. A canopy-coverage method of vegetational analysis. Northwest Science. 33: 43-64.

Daubenmire, R. F. 1970. Steppe vegetation of Washington. Tech. Bull. 62. Pullman, WA: Washington Agricultural Experiment Station. 131 p.

Guenther, G. E. 1989. Ecological relationships of bitterbrush communities on the Mount Haggin Wildlife Management Area. Helena, MT: Montana Department of Fish, Wildlife, and Parks; Department of Animal and Range Sciences, Montana State University. 73 p.

Hamlin, K. L.; Mackie, R. J. 1989. Mule deer in the Missouri River Breaks, Montana. Helena, MT: Montana Department of Fish, Wildlife, and Parks. 401 p.

Harniss, R. O.; Murray, R. B. 1973. Thirty years of vegetal change following burning of sagebrush, grass range. Journal of Range Management. 26: 322-325.

Hironaka, M. M.; Fosberg, M.; Winward, A. H. 1983. Sagebrush-grass habitat types of southern Idaho. Bull. 35. Moscow, ID: University of Idaho, Forestry, Wildlife and Range Experiment Station. 41 p.

Johnson, A. H.; Strang, R. M. 1983. Burning in a bunchgrass/sagebrush community: the southern interior of British Columbia and northwestern U.S. compared. Journal of Range Management. 36: 616-617.

Jones, R. D. 1983. Rotomowing antelope bitterbrush—preliminary report. In: Tiedemann, A. R.; Johnson, K. L., compilers. Proceedings—research and management of bitterbrush and cliffrose in western North America; 1982 April 13-15; Salt Lake City, UT. Gen. Tech. Rep. INT-152. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 158-162.

Klebenow, D. A. 1985. Big game response to fire in sagebrush-grass rangelands. In: Sanders, K.; Durham, J., eds. Rangeland fire effects—a symposium; 1984 September 27-29;

Boise, ID. Boise, ID: Bureau of Land Management and University of Idaho: 61-65.

Kufeld, R. C. 1973. Foods eaten by the Rocky Mountain elk. Journal of Range Management. 26: 106-113.

Kufeld, R. C.; Wallmo, O. C.; Feddema, C. 1973. Foods of the Rocky Mountain mule deer. Res. Pap. RM-111. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 31 p.

Kuntz, D. E. 1982. Plant response following spring prescribed burning in an *Artemisia tridentata* ssp. *vaseyana/ Festuca idahoensis* habitat type. Moscow, ID: University of Idaho. 73 p. Thesis.

Lonner, T. N. 1972. Age distribution of key browse plants in Montana. Bozeman, MT: Montana State University. 79 p. Thesis.

Lund, R. 1991. MSUSTAT statistical analysis package, microcomputer version 5.00. Bozeman, MT: Montana State University.

Mangan, L.; Autenrieth, R. 1985. Vegetation changes following 2,4-D application and fire in a mountain big sagebrush habitat type. In: Sanders, K.; Durham, J., eds. Rangeland fire effects—a symposium; 1984 September 27-29; Boise, ID. Boise, ID: Bureau of Land Management and University of Idaho: 61-65.

Martin, N.; Pyrah, D. 1971. Sage grouse. In: Mussehl, T. W.; Howell, F. W., eds. Game management in Montana. Helena, MT: Montana Game and Fish Department, Game Division: 135-141.

Martin, R. E.; Driver, C. H. 1983. Factors affecting antelope bitterbrush reestablishment following fire. In: Tiedemann, A. R.; Johnson, K. L., compilers. Proceedings—research and management of bitterbrush and cliffrose in western North America; 1982 April 13-15; Salt Lake City, UT. Gen. Tech. Rep. INT-152. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 266-279.

McArthur, E. D.; Stutz, H. C.; Sanderson, S. C. 1983. Taxonomy, distribution, and cytogenetics of *Purshia, Cowania* and *Fallugia* (Rosoideae, Rosaceae). In: Tiedemann, A. R.; Johnson, K. L., compilers. Proceedings—research and management of bitterbrush and cliffrose in western North America; 1982 April 13-15; Salt Lake City, UT. Gen. Tech. Rep. INT-152. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 4-24.

McNeal, A. F. 1984. Site characteristics and effect on elk and mule deer use of the Gardiner winter range, Montana. Bozeman, MT: Montana State University. 133 p. Thesis.

Monsen, S. B.; Shaw, N. L. 1983. Seeding antelope bitterbrush with grasses on south-central Idaho rangelands— a 39-year response. In: Tiedemann, A. R.; Johnson, K. L., compilers. Proceedings—research and management of bitterbrush and cliffrose in western North America; 1982 April 13-15; Salt Lake City, UT. Gen. Tech. Rep. INT-152. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 126-136.

Mueggler, W.; Stewart, W. L. 1980. Grassland and shrubland habitat types of western Montana. Gen. Tech. Rep. INT-66. Ogden, UT: U.S. Department of Agriculture,

Forest Service, Intermountain Forest and Range Experiment Station. 154 p.

Murray, R. 1983. Response of antelope bitterbrush to burning and spraying in southeastern Idaho. In: Tiedemann, A. R.; Johnson, K. L., compilers. Proceedings—research and management of bitterbrush and cliffrose in western North America; 1982 April 13-15; Salt Lake City, UT. Gen. Tech. Rep. INT-152. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 142-152.

Nimir, M. B.; Payne, G. F. 1978. Effects of spring burning on a mountain range. Journal of Range Management. 31: 259-263.

NOAA. 1990. Climatological data, Montana. Asheville, NC: National Climatic Data Center. 84-93(1-13).

Nord, E. C. 1965. Autecology of bitterbrush in California. Ecological Monographs. 35: 307-334.

Pechanec, J. F.; Stewart, G.; Blaisdell, J. P. 1954. Sagebrush burning—good and bad. Farmers Bull. 1948. Washington, DC: U.S. Department of Agriculture. 34 p.

Peek, J. M.; Riggs, R. A.; Lauer, J. L. 1979. Evaluation of fall burning on big horn sheep winter range. Journal of Range Management. 32: 430-432.

Pickford, G. D. 1932. The influence of continual heavy grazing and of promiscuous burning on spring-fall ranges in Utah. Ecology. 13: 159-171.

Ralphs, M. H.; Schen, D.; Busby, F. E. 1975. Prescribed burning—effective control of sagebrush and open juniper. Utah Science. 36: 94-98.

Rice, C. L. 1983. A literature review of the fire relationships of antelope bitterbrush. In: Tiedemann, A. R.; Johnson, K. L., compilers. Proceedings—research and management of bitterbrush and cliffrose in western North America; 1982 April 13-15; Salt Lake City, UT. Gen. Tech. Rep. INT-152. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 256-265.

Ross, R. L.; Hunter, H. E. 1976. Climax vegetation of Montana. Bozeman, MT: U.S. Department of Agriculture, Soil Conservation Service. 64 p.

Rotenberry, J. T.; Wiens, J. A. 1978. Nongame bird communities in northwestern rangelands. In: DeGraaf, R. M., tech. coord. Workshop on nongame bird habitat management in coniferous forests of the western U.S.; 1977 February 7-9; Portland, OR. Gen. Tech. Rep. PNW-64. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 32-46.

Sturges, D. L.; Nelson, D. L. 1986. Snow depth and incidence of a snowmold disease on mountain big sagebrush. In: McArthur, E. D.; Welch, B. L., compilers. Proceedings— Symposium on the biology of *Artemisia* and *Chrysothamnus*; 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 215-221.

Uresk, D. W.; Cline, J. F.; Rickard, W. H. 1976. Impact of wildfire on 3 perennial grasses in south-central Washington. Journal of Range Management. 29: 309-310.

U.S. Department of Agriculture. 1981. Bull Run allotment burn plan. Butte, MT: U.S. Department of Agriculture, Forest Service, Deerlodge National Forest, Butte Ranger District. 3 p.

COMPARISON OF THREE GROUPS OF VARIABLES FOR PREDICTING BIG SAGEBRUSH FORAGE PRODUCTION

W. H. Creamer IV
C. L. Wambolt
R. J. Rossi

ABSTRACT

Reports modeling procedures used to develop regression equations to predict forage production available in the winter from Wyoming big sagebrush (Artemisia tridentata ssp. wyomingensis), *mountain big sagebrush (A.t. ssp. vaseyana), and basin big sagebrush (A.t. ssp. tridentata) in high- and low-use form classes. Measurements of maximum diameter, minimum diameter, height, crown depth, average cover, and combinations of these measurements were used. Scatter diagrams indicated linear relationships between the dependent and independent variables. Colinearity analysis indicated strong linear relationships among maximum diameter, minimum diameter, and elliptical area. Therefore, three groups of variables based on these parameters were used in modeling.*

INTRODUCTION

Big sagebush (*Artemisia tridentata* Nutt.) is the most widespread and abundant shrub on rangelands of the Western United States (McArthur and others 1979); it dominates over 58 hectares in the 11 Western States (Beetle 1960). Big sagebrush provides cover and forage for a variety of rangeland wildlife species. Elk (*Cervus elaphus nelsoni*) and mule deer (*Odocoileus hemionus*) browse sagebrush heavily during the fall and winter on our study area (McNeal 1984). The distributions of pronghorn antelope (*Antilocarpa americana*) and sage grouse (*Centrocercus urophasianus*) are closely associated with the distribution of big sagebrush (Roberson 1984; Sundstrom 1973). It provides important cover for elk calving, waterfowl and songbird nesting, and small mammals (Ewaschuk and Boag 1972).

The high forage and other habitat values of sagebrush make it important for range managers to accurately estimate forage production. A procedure to predict the forage produced by the sagebrush complex will be helpful to determine carrying capacity of the range, to detect trends in forage production, and to measure plant response to management. Methods that involve clipping or harvesting are costly, time consuming, and destructive (Uresk and others 1977). Nondestructive procedures based on easily meas-ured plant dimensions to estimate production and biomass have been developed for a variety of other plants (Andrew and others 1979; Pechanec and Pickford 1937; Tufts 1919; Weaver 1977).

Mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana* [Rydb.] Beetle), Wyoming big sagebrush (*A.t.* ssp. *wyomingensis* Beetle and Young), and basin big sagebrush (*A.t.* ssp. *tridentata*) were of interest for this study. Differences in growth form, distribution, ecology, phenology, animal preference, and forage qualities are well defined among these subspecies (Beetle 1960; Depuit and Caldwell 1973; Harvey 1981; Kelsey and others 1976; Morris and others 1976; Personius and others 1987; Striby and others 1987; Wambolt and McNeal 1987; Welch and Pederson 1981; Winward 1970). While taxonomic differences may be subtle, regression equations used to predict forage production for each subspecies may be unique. Previous browsing, as it affects shrub morphology, may also affect prediction equations (Hughes and others 1987).

The objective of this paper is to report the identification of efficient and effective modeling procedures that avoid including colinear variables for prediction of big sagebrush forage production. This came from a comprehensive study to develop regression equations using easily measured plant dimensions to accurately predict forage production for mountain, Wyoming, and basin big sagebrush, and to determine any effects of past browsing on regression equations.

STUDY AREA

The study area is located near Gardiner in the Gallatin National Forest of southwestern Montana. Gardiner lies in the Yellowstone River valley at 1,694 m (5,505 ft) surrounded by peaks reaching 3,353 m (11,000 ft). Average annual precipitation over 100 years is 41.2 cm (16.25 inches) at Gardiner. The rain shadow produced by the mountains makes the benches and slopes of the Gardiner

valley an important wintering area for mule deer and elk, while bison, bighorn sheep, and antelope also use some portions of the area.

Vegetation is predominantly sagebrush-grassland. The three subspecies of big sagebrush we studied and black sagebrush (*Artemisia nova* A. Nels.) occur sympatrically throughout the study area.

MEASUREMENTS

Stands of mountain, Wyoming, and basin big sagebrush were located in both high- and low-use form classes during June of 1989. Subspecies were identified morphologically (Beetle 1960) and later verified using an ultraviolet light (Stevens and McArthur 1974). Form class was determined by the overall appearance of each shrub. Different browsing levels by elk and mule deer on the study area over a number of years have resulted in very distinct growth forms. Browsing over time has produced shorter, more intricately branched crowns. This has given heavily browsed plants dense, hedged, clublike forms. Lightly browsed plants exhibit longer leaders and a less dense appearance as the crowns are more open, growthy, and relatively unbranched. High-use stands were located on south- or west-facing slopes in remote areas. Stands of low-use plants were situated near human occupation or other interference that inhibited elk and mule deer use, and in one case, where deep snows prevented winter access. The following six stands were located: high-use Wyoming big sagebrush (ATWH), low-use Wyoming big sagebrush (ATWL), high-use mountain big sagebrush (ATVH), low-use mountain big sagebrush (ATVL), high-use basin big sagebrush (ATTH), and low-use basin big sagebrush (ATTL).

Sampling started in late July 1989 and continued through September 1989. This allowed for the nearly complete abscission of the ephemeral leaves, which are not considered available winter browse. Only the current crop of perennial leaves persists over winter (Miller and Shultz 1987).

Overall height (*HT*) of each sagebrush plant was measured (to the nearest centimeter) from the ground to the highest nonreproductive foliage. We were interested in forage available to deer and elk; therefore, the maximum plant height was set at 140 cm (55 inches). Mountain and Wyoming big sagebrush heights did not exceed this limit. However, some basin big sagebrush plants attained heights above 140 cm and therefore were not sampled.

Two measurements of crown width were taken (Rittenhouse and Sneva 1977). The major axis (*MJ*) was considered to be the maximum horizontal distance across the plant crown inclusive of only living plant tissue. The minor axis (*MN*) was the maximum crown width perpendicular to the major axis, again for only living tissue. Although photosynthetic plant tissue was used for the beginning and the end of these axes, nonphotosynthetic canopy openings are included in these measurements. All measurements were to the nearest centimeter.

Line intercept canopy cover (*AC*) measurements (Canfield 1941) were taken of actively growing plant material. This included perennial leaves, current growth twigs, and reproductive stalks. Cover was measured along the major and minor axes and two additional perpendicular axes at 45 degrees to the intersection of the major and minor axes and then averaged.

Crown depth (*CD*) was the vertical distance in centimeters of the portion of the crown foliated by vegetative leaders (Dean and others 1981). Several measurements were averaged for each plant.

Forage weight (*F*), was the dependent variable for the regression analysis. After obtaining the measurements, perennial leaves, ephemeral leaves (if any), and current twig growth were removed from the plant. Young twigs were easily discernible on the basis of color, texture of the bark, and leaf bud scars. Although browsing ungulates may remove more than current twig growth, we only considered current year's leaders and foliage. After ovendrying for 48 hours at 60 °C the foliage was weighed to the nearest 0.1 g.

The field measurements were used to derive other variables for the regression analysis. These were elliptical crown area, crown volume, shrub volume, and circular crown areas based on two different crown radii. Elliptical canopy area was determined by the formula $E = \pi (MJ/2)(MN/2)$. Crown volume was then defined as $CV = E(CD)$. Shrub volume was defined as $SV = E(HT)$. Peek (1970) and Harvey (1981) refer to this variable as crown volume.

The crowns of heavily browsed plants appeared more rounded, so circular crown areas were considered (Murray and Jacobson 1982). Two variables that represent circular area of the canopy were investigated: (a) the circular area (*C1*) for the major axis from the formula, $C1 = \pi (MJ/2)^2$, and (b) the circular area (*C2*) for the minor axis from the formula $C2 = \pi (MN/2)^2$.

STATISTICAL ANALYSIS

Models were evaluated with adjusted R^2 values where $R_a^2 = 1-(n-1/n-p) * \text{SSERR/SSTOT}$. The adjusted R^2 statistic is calculated by adjusting the coefficient of determination (R^2) for the number of parameters in the model and the sample size. This adjustment prevents the R^2 statistic from becoming artificially inflated as the number of variables in the model increases (Neter and others 1985). Adjusted R^2 values are generally similar to R^2 values, though somewhat smaller.

Scatter diagrams were constructed for each independent variable and the dependent variable to identify linear and curvilinear tendencies. The variable *HT* for low-use mountain big sagebrush (ATVL) was the only variable determined to have a curvilinear relationship with the dependent variable (*F*) and was added to the model as HT^2 for ATVL. The dependent variable (*F*) was log transformed (natural logarithm) to stabilize nonconstant variance exhibited in the residual plots. Nonconstant variance was a direct result of stratified random sampling used to obtain a representative sample of different-sized shrubs at each site. The log transformation is a powerful variance stabilizing transformation and widely used (Dean and others 1981; Murray and Jacobson 1977; Rittenhouse and Sneva 1977).

Colinearity analysis for each taxon and form class combination identified colinearities among some of the variables. The variables *MJ* and *MN* were determined to

Table 1—Groups of independent variables.[1] Each variable group includes only major axis (MJ), minor axis (MN), or elliptical area (E) in addition to the other variables measured

Group 1	Group 2	Group 3
MJ	MN	E
HT	HT	HT
HT²	HT²	HT²
CD	CD	CD
AC	AC	AC
C1	C2	CV
		SV

[1]Variable abbreviations: MJ - major axis, MN - minor axis, E - elliptical area, HT - height, HT² (for ATVL only), CD - crown depth, AC - average cover, C1 - circular area 1, C2 - circular area 2, CV - crown volume, V - shrub volume.

be nearly colinear with each other and also with the variable E, caused by the consistently similar shape of the crowns. Information contained in each of the three variables is nearly identical, thus including more than one of these three variables in a model is inappropriate (Neter and others 1985). Variables were separated into three groups to split up the variables MJ, MN, and E and thereby avoid colinearities (table 1). Each of three groups of independent variables was analyzed in the model-building procedure to select the best prediction model with each taxon and form class combination. Models are of the form:

$$\ln(F) = b_0 + X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + e$$

where

F = available winter forage
b_0 = y-intercept
X_1 = major (MJ) or minor (MN) axis or elliptical area (E)
X_2 = height (HT)
X_3 = HT^2 for low-use mountain big sagebrush (ATVL) only
X_4 = crown depth (CD)
X_5 = average cover (AC)
X_6 = circular area 1 ($C1$) or circular area 2 ($C2$) or crown volume (CV)
X_7 = shrub volume (SV)
e = residual error
All X_n terms have an associated constant = b_n.

RESULTS AND DISCUSSION

Colinearities among the variables MJ, MN, and E mandated the investigation of three variable groups (table 1) in the model-building process. Table 2 indicates that differences among the three variable groups are small in adjusted R^2 values. That is, each variable group predicts annual winter forage production for all three subspecies and form classes of big sagebrush with essentially the same efficiency.

Colinearity analysis indicated that the three variables MJ, MN, and E all have strong linear relationships with each other. Scatter plots of MJ vs. MN for each subspecies and form class revealed a linear relationship for these variables in each case. This evidence indicates that MJ is essentially equal to MN for each taxon and form class combination. Mathematically, E approaches the value of MJ times MN as the constants are absorbed in the b_n term in the regression equation. If $MJ = MN$, then E is equal to $MJ^2 = MN^2$. Scatter plots of E vs. MJ^2 and MN^2 show a strong linear relationship as expected. In the model-building process, for this data set, the variables major axis, minor axis, and elliptical area all describe the same information and the three variable groups each describe the same relationships.

Difficulties in identifying the big sagebrush subspecies are well known (Winward and Tisdale 1977). Nevertheless, differentiation of big sagebrush subspecies is important in analyzing site potential and condition (Dean and others 1981), identifying animal preferences (Personius and others 1987; Welch and Pederson 1981), and predicting treatment response. Even though the prediction equations for low-use Wyoming big sagebrush and low-use mountain big sagebrush use the same variables, the y-intercept and the associated coefficients in each equation are quite different. Different regression equations for each subspecies greatly increased precision in predicting forage production, thereby demonstrating the value of subspecies recognition.

Heavy previous use can be considered a treatment that affects growth form (Patton and Hall 1966). Hughes and others (1987) found that while range site did not affect prediction equations, mechanical treatment (shredding) did. They concluded that treatments that greatly modify plant form will probably require regression equations different from those of undisturbed vegetation. Our findings are consistent with this premise, as separate prediction equations were developed for each form class with a consequent increase in precision.

If a strict random sampling technique can be applied, a transformation of variables may be avoided, as the error terms would also be randomly distributed. But a stratified sample is often desirable when there are risks that a random sample may not satisfactorily represent the population. This may be the case with determination of annual winter forage production from big sagebrush taxa, since sampling time is limited to the rather short period between ephemeral leaf drop and winter.

Other researchers have developed log-log equations for predicting various components of big sagebrush (Dean and others 1981; Hughes and others 1987; Rittenhouse and Sneva 1977). Tausch (1989) determined that systematic bias from log-log transformations with a specified nonlinear model is an important factor to consider in biomass estimation. In this study, linear regression was justified by the fact that nonlinear relationships were not indicated in the scatter plots of dependent versus independent variables.

Colinearity analysis indicated that the variables MJ, MN, and E should not be used in the same equation. This resulted in somewhat different final equations (not reported here) than those reported by other researchers. Rittenhouse and Sneva (1977) combined these variables in some of their higher R^2 models. Dean and others

219

Table 2—Highest adjusted R^2 and R^2 values for each subspecies and form class combination using the three variable groups from table 1

	Taxon and form class[1]	ATVL	ATVH	ATWL	ATWH	ATTL	ATTH
Group 1	Adj. R^2	0.88	0.90	0.88	0.84	0.78	0.88
models	R^2	.89	.91	.90	.86	.82	.89
based on *MJ*	Root MSE[2]	.35	.24	.24	.26	.35	.21
Group 2	Adj. R^2	.89	.89	.81	.84	.73	.89
models	R^2	.90	.91	.83	.87	.75	.91
based on *MN*	Root MSE	.34	.25	.30	.26	.40	.20
Group 3	Adj. R^2	.81	.90	.83	.85	.78	.88
models	R^2	.83	.92	.87	.88	.82	.89
based on *E*	Root MSE	.44	.23	.28	.25	.36	.21

[1]Abbreviations for taxon and form class: ATVL - low-use mountain big sagebrush, ATVH - high-use mountain big sagebrush, ATTL - low-use basin big sagebrush, ATTH - high-use basin big sagebrush, ATWL - low-use Wyoming big sagebrush, ATWH - high-use Wyoming big sagebrush.

[2]Root MSE = MSE$^{1/2}$.

(1981) also used measures of maximum and minimum diameters together in the best-fit equations that they reported. These studies do not mention colinearity. If colinearities among maximum diameter, minimum diameter, and elliptical areas were not indicated for their data, then it would seem that the overall shape of big sagebrush is more variable from site to site than generally known. The colinearity diagnostics determine the appropriateness of including different variables in the same regression equation, and increase efficiency by avoiding collection of redundant measurements.

REFERENCES

Andrew, M. H.; Noble, I. R.; Lange, R. T. 1979. A nondestructive method for estimating the weight of forage on shrubs. Australian Rangeland Journal. 1: 225-231.

Beetle, A. A. 1960. A study of sagebrush, the section *Tridentatae* of *Artemisia*. Bull. 368. Laramie, WY: Wyoming Agricultural Experiment Station. 83 p.

Canfield, R. H. 1941. Application of the line interception method in sampling range vegetation. Journal of Forestry. 39: 388-394.

Dean, S.; Burkhardt, J. W.; Meeuwig, R. O. 1981. Estimating twig and foliage biomass of sagebrush, bitterbrush, and rabbitbrush in the Great Basin. Journal of Range Management. 34: 224-227.

Depuit, E. J.; Caldwell, M. M. 1973. Seasonal pattern of net photosynthesis of *Artemisia tridentata*. American Journal of Botany. 60: 426-435.

Ewaschuk, E.; Boag, D. A. 1972. Factors affecting hatching success of densely nesting Canada geese. Journal of Wildlife Management. 36(4): 1097-1106.

Harvey, S. J. 1981. Life history and reproductive strategies in *Artemisia*. Bozeman, MT: Montana State University. 132 p. Thesis.

Hughes, G.; Varner, L. G.; Blankenship, L. H. 1987. Estimating shrub production from plant dimensions. Journal of Range Management. 40: 367-369.

Kelsey, R. G.; Morris, M. S.; Shafizadeh, F. 1976. The use of sesquiterpene lactones as taxonomic markers in the shrubby species of *Artemisia* (section *Tridentatae*) in Montana. Journal of Range Management. 29(6): 502-505.

McArthur, E. D.; Blauer, A. C.; Plummer, A. P.; Stevens, R. 1979. Characteristics and hybridization of important intermountain shrubs. III. Sunflower family. Res. Pap. INT-220. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 82 p.

McNeal, A. F. 1984. Site characteristics and effects on elk and mule deer use on the Gardiner winter range, Montana. Bozeman, MT: Montana State University. 133 p. Thesis.

Miller, R. F.; Shultz, L. M. 1987. Development and longevity of ephemeral and perennial leaves on *Artemisia tridentata* Nutt. ssp. *wyomingensis*. Great Basin Naturalist. 47(2): 227-230.

Morris, M. S.; Kelsey, R. G.; Griggs, D. 1976. The geographic and ecological distribution of big sagebrush and other woody *Artemisias* in Montana. Proceedings Montana Academy of Science. 36: 56-79.

Murray, R. B.; Jacobson, M. Q. 1982. An evaluation of dimension analysis for predicting shrub biomass. Journal of Range Management. 35: 451-454.

Neter, J.; Wasserman, M.; Kutner, M. H. 1985. Applied linear statistical models. 2d ed. Homewood, IL: Richard D. Irwin, Inc. 1127 p.

Patton, A. J.; Hall, D. F. 1966. Evaluating key browse areas. Journal of Wildlife Management. 30: 477-480.

Pechanec, J. F.; Pickford, G. D. 1937. A weight estimate method for determination of range or pasture production. Journal of the American Society of Agronomy. 29: 894-904.

Peek, J. M. 1970. Relationship of canopy area and volume to production of three woody species. Ecology. 51: 1098-1101.

Personius, T. L.; Wambolt, C. L.; Stephens, J. R.; Kelsey, R. G. 1987. Crude terpenoid influence on mule deer preference for sagebrush. Journal of Range Management. 40(1): 84-88.

Rittenhouse, L. R.; Sneva, F. A. 1977. A technique for estimating big sagebrush production. Journal of Range Management. 30: 68-70.

Roberson, J. A. 1984. Sage grouse-sagebrush relationships: a review. In: McArthur, E. D.; Welch, B. L., compilers. Proceedings—symposium on the biology of *Artemisia* and *Chrysothamnus*; 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 157-167.

Stevens, R.; McArthur, E. D. 1974. A simple field technique for identification of some sagebrush taxa. Journal of Range Management. 27: 325-326.

Striby, K. D.; Wambolt, C. L.; Kelsey, R. G.; Havstad, K. M. 1987. Crude terpenoid influence on in vitro digestibility of sagebrush. Journal of Range Management. 40(3): 244-248.

Sundstrom, C. 1973. Abundance, distribution and food habits of the pronghorn. Bull. 12. Cheyenne, WY: Wyoming Game and Fish Commission. 62 p.

Tausch, R. J. 1989. Comparison of regression methods for biomass estimation of sagebrush and bunchgrass. Great Basin Naturalist. 49: 373-380.

Tufts, W. P. 1919. Pruning of deciduous fruit trees. Bull. 313. California Agricultural Experiment Station. 11 p.

Uresk, D. W.; Gilbert, R. O.; Rickard, W. H. 1977. Sampling big sagebrush for phytomass. Journal of Range Management. 30: 311-314.

Wambolt, C. L.; McNeal, A. F. 1987. Selection of winter foraging sites by elk and mule deer. Journal of Environmental Management. 25: 285-291.

Weaver, T. 1977. Area-mass relationships for common Montana shrubs. Proceedings Montana Academy of Science. 37: 54-58.

Welch, B. L.; Pederson, J. C. 1981. In vitro digestibility among accessions of big sagebrush by wild mule deer and its relationship to monoterpenoid content. Journal of Range Management. 34(6): 497-500.

Winward, A. H. 1970. Taxonomic and ecological relationships of the big sagebrush complex in Idaho. Moscow, ID: University of Idaho. 80 p. Thesis.

Winward, A. H.; Tisdale, E. W. 1977. Taxonomy of the *Artemisia tridentata* complex in Idaho. Bull. 19. Moscow, ID: University of Idaho, College of Forestry, Wildlife and Range Sciences. 15 p.

Section 5—Field Trips

CAMAS PRAIRIE AND POSSIBLE EVOLUTIONARY LINKS WITH OLD WORLD *ARTEMISIA* SPECIES: A PRESYMPOSIUM TOUR

Roger Rosentreter

ABSTRACT

Describes a field trip, which may be adapted to do-it-yourself visits, through Camas Prairie on the route between Boise and Sun Valley, ID. Stops provide opportunities to study the geology, soils, and remnant native vegetation of the area. The author concludes with observations on the possible evolution of woody sagebrush species in North America.

INTRODUCTION

The 1991 Wildland Shrub Symposium was held in Sun Valley, ID. The lack of a major airline service to Sun Valley afforded an opportunity for a presymposium tour of the route between Boise and Sun Valley. The main focus of the tour was to observe remnant native vegetation in the Camas Prairie near Fairfield, ID. This prairie contains many interesting shrubs, but in contrast to much of the West, it contains little publicly owned land. Therefore, most of Camas Prairie has been converted to agricultural production. The opportunity to examine remnant native vegetation and some of these interesting shrubs led to scheduling the tour.

History

The present-day natural history of the Camas Prairie and its human history are closely intertwined. Dramatic changes occurred as Euroamericans began to settle the area. First, beaver populations, important for regulating stream flows, were decimated by trappers. Second, Native Americans, who had visited the Prairie for centuries on their annual search for camas (*Camassia quamash*) roots, were discouraged from continuing the ritual. This resulted from the introduction of domestic pigs, which uprooted and destroyed the camas crop, a crucial food source for the native people (Conley 1982; Quinney 1991).

Pigs were used extensively. Some were kept near the settlers' homesteads, while others ranged throughout the Prairie, causing great concern among the natives. Several white settlers were killed in retaliation for loss of the camas crop, spawning what is now known as the Sheepeater War (Conley 1982).

Geology/Soils

The Camas Prairie, between 5,000 ft (1,530 m) and 5,300 ft (1,620 m) in elevation, is a large, relatively flat region dominated by basalt. It is isolated from the Snake River Plains Basalt by the Bennett Hills, a granitic mountain range. The Camas Prairie Basalt flow is chemically distinct from both the Snake River and the Columbia River basalt flows (Maley 1991). However, while each flow has its unique chemistry, all have similar physical properties.

Mountain ranges surround it on all sides, providing drainage into the prairie. The basalt bedrock and influx of volcanic ash from Mount Mazama and other volcanos over time have produced soils with a high clay content. These clay soils restrict drainage, producing highly saturated ground throughout the prairie during spring runoff. The soils of the Camas Prairie are influenced by rather frigid climatic conditions and seasonally saturated soils. These conditions provide optimal habitat for the growth of silver sagebrush (*Artemisia cana*) and camas.

Nomenclature

Nomenclature of vascular plants not referenced follows Hitchcock and Cronquist (1973), except *Artemisia*, which follows that used by Beetle (1960) and McArthur and Plummer (1978). Nomenclature of lichens follows Egan (1987).

TOUR ROUTE

The tour route (see fig. 1) and schedule are outlined here. The tour left Boise on May 28, 1991. We traveled east from Boise on I-84 to its junction with Route 20, and then traveled northeast and east via Route 20 to its junction with Route 93, then northward to Sun Valley.

Stop #1—Snake River Plains

At the southeastern corner of the junction of I-84 and Simco Road is a relatively pristine Wyoming big sagebrush/Thurber needlegrass-bluebunch wheatgrass (*Artemisia tridentata* ssp. *wyomingensis*/*Stipa thurberiana*-*Agropyron spicatum*) habitat type, with many soil microplants (cryptogams) in the interspaces. Much of the lower Snake River
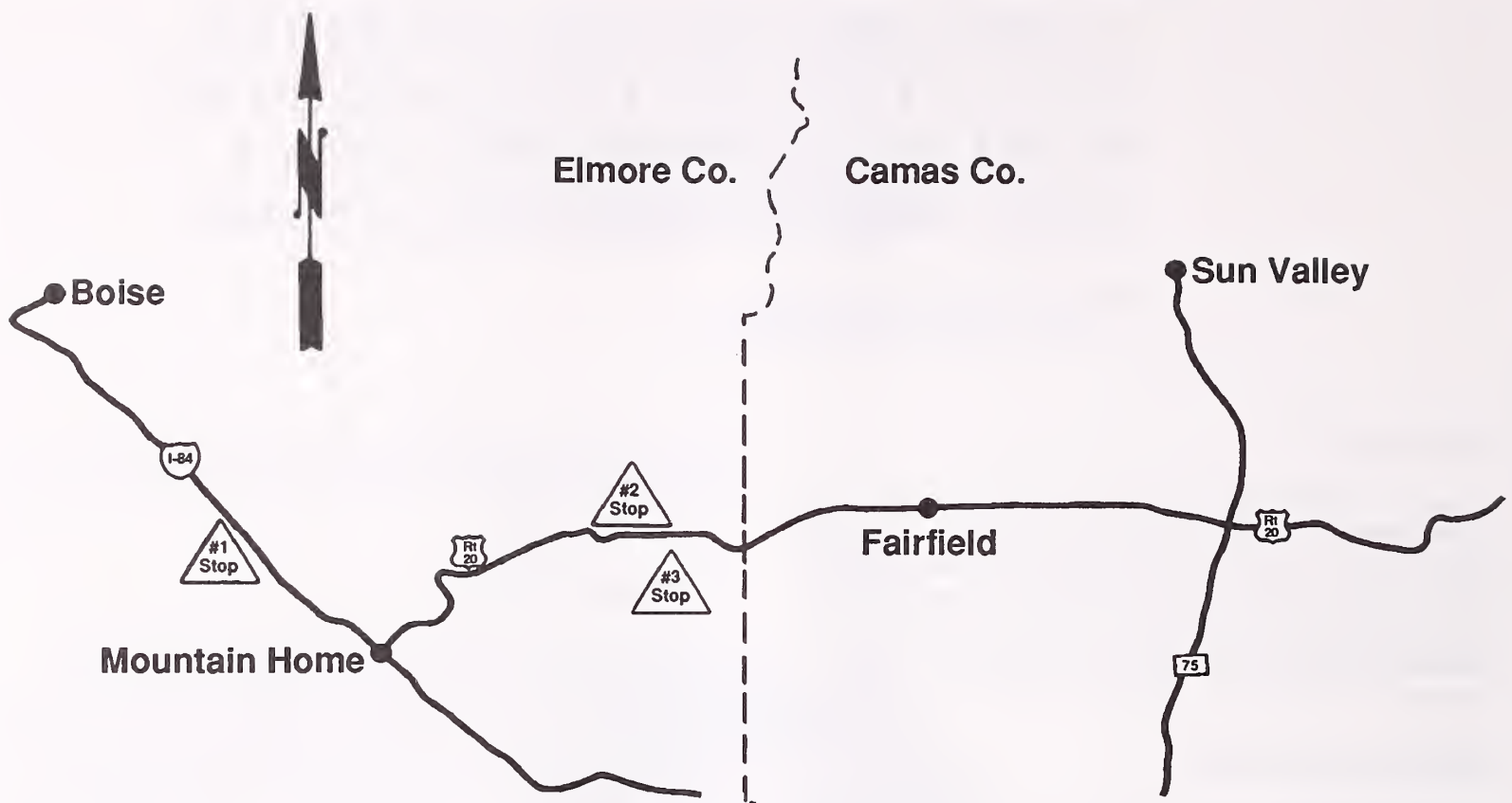
Figure 1—Presymposium tour route, Boise to Sun Valley, ID.

Plain has been degraded and converted to annual grassland, making this site a valuable, but undesignated, rangeland reference area. There is a limited amount of cheatgrass (*Bromus tectorum*) and a high percentage cover of perennial bunchgrasses. Canopy cover of shrubs is low, estimated at 15 to 20 percent. The shrubs are easy to walk between, and interspaces are literally carpeted with microplants that form a mulch over the soil surface. Some of the common microplants were identified and their benefits in retaining soil moisture discussed. Common microplants at this site include twisted moss (*Tortula ruralis*), wall lichen (*Lecanora muralis*), cowpie lichen (*Diploschistes muscorum*), soil dot lichen (*Psora* spp.), and creeping coral lichen (*Aspicilia reptans*). The soils are derived from granitic alluvium and volcanic ash deposited over the alluvium. There is a restricted duripan or calcic horizon at less than 40 inches. Soils are of the Sebree series, and are classified as fine-silty, mixed, Xerollic Nadurargids.

Continue onward via I-84 to exit 95, taking Route 20 north to Sun Valley. Leaving the shallow soils of the Snake River Plains, the topography, soils, and vegetation abruptly change. As you climb the hills toward the Camas Prairie, deeper soils derived from coarse-grained rhyolite and granite support mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) and bluebunch wheatgrass. There are stream bottoms along this front of the Bennett Hills where basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*) occurs in deeper alluvium soils along ephemeral washes. The transition from one dominant subspecies of sagebrush to another is particularly striking. In these areas all three common big sagebrush subspecies, basin, Wyoming, and mountain, occur within sight of each other, though on three different soil types.

Continuing up the hill, Palmer penstemon (*Penstemon palmeri*) is observed growing in the highway right-of-way. The Idaho State Highway Department uses this species and, although Palmer penstemon is native to southern Utah, it is successfully reseeding itself in this area of coarse-textured soils. The route continues on rhyolite referred to as the Bennett Hills Formation to the Boise National Forest boundary and sign, where it enters granitic bedrock of the Alantic lobe of the Idaho Batholith. Its pattern of weathering into hoodoos and pinnacles is seen at the next stop and at other points along the route.

Stop #2—Scenic Overlook

The scenic overlook is at Milepost 124.5 and is well marked by interpretive signs. One is provided with an excellent overview of the Alantic lobe of the Idaho Batholith from this point. The vegetation surrounding the overlook has recently burned (1990), and white rubber rabbitbrush (*Chrysothamnus nauseosus* ssp. *albicaulis*) has resprouted profusely.

Stop #3—Camas Prairie, Shallow Soils

At Milepost 130 is the Camas Prairie shallow-soil site. Noticeably rocky, the site is north of the highway and has a large turnout for parking nearby. Fuzzy sagebrush (*Artemisia papposa*) communities are present in this area (fig. 2). Fuzzy sagebrush occupies sites with shallow, stony basalt and frigid, heavy clay soils that are ephemerally flooded from late winter to early spring. This soil condition occurs infrequently and is not included in a standard soil series. It can be classified as a Lithic Argixeroll. Fuzzy sagebrush

is restricted to midelevation sites 4,000 to 6,500 ft (1,220 to 1,950 m) in elevation on basalt soils in southwestern Idaho and southeastern Oregon (Hall and Clements 1923; McArthur and Plummer 1978) (fig. 3). Thyme-leaf and mat buckwheat (*Eriogonum thymoides* and *E. caespitosum*, respectively) occur as dwarf shrubs. Other associated species include lava aster (*Aster scopulorum*), stoloniferous everlasting (*Antennaria flagellaris*), one-spike danthonia (*Danthonia unispicata*), western needlegrass (*Stipa occidentalis*), and barestem lomatium (*Lomatium nudicale*). Rocks are heavily colonized by a variety of lichens, including silver-skinned lichen (*Dermatocarpon reticulatum*). The presence of this

Figure 2—Shows the shallow rocky soils in which fuzzy sagebrush occurs. The pointer focuses on a pencil to illustrate the small size of the plant.

▲ = *Artemisia papposa* (fuzzy sagebrush)
✱ = *Artemisia longiloba* (early sagebrush)
■ = *Artemisia rigida* (scabland sagebrush)
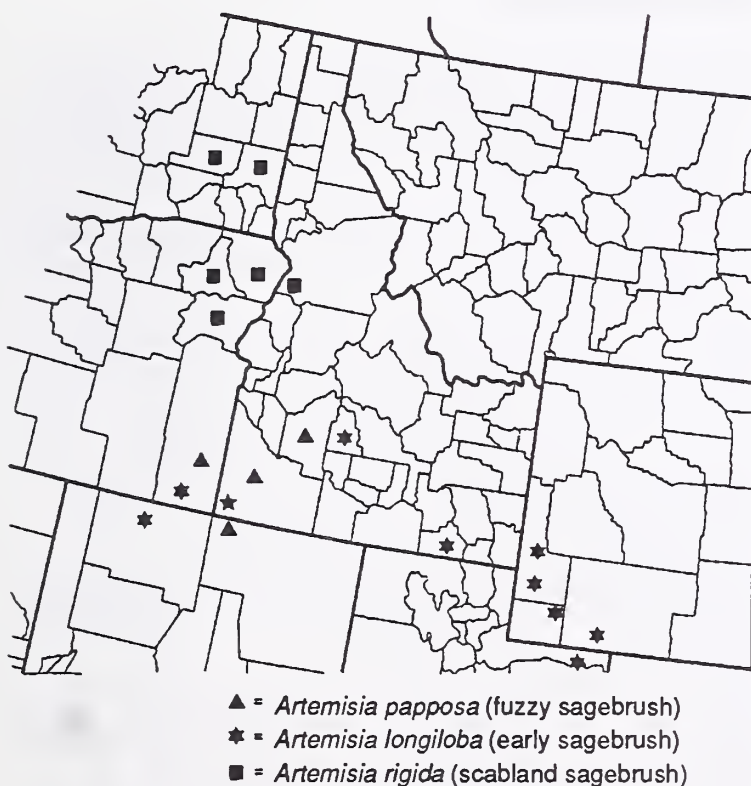
Figure 3—Distribution of the very shallow, ephemerally wet *Artemisia* species in western North America (modified from Shultz 1986).

lichen, often considered an aquatic species of streams and ephemeral drainages, is an indicator of the saturated conditions in the spring.

Fuzzy sagebrush flowers in early summer unlike most other woody sagebrush species, which flower in the fall. I have observed that sheep, which graze this area in spring and fall, heavily utilize the flower stalks of fuzzy sagebrush during the month of September. Utilization of flower stalks is unusual among the sagebrushes, as other sagebrush species contain a large amount of secondary metabolic chemicals in their flower stalks that protects them from utilization by livestock or insects (Kelsey and others 1984). Mature seeds of fuzzy sagebrush also provide a high-protein food source.

Stop #4—Camas Prairie, Deeper Soils

Near Milepost 136, one-half mile west of the Elmore-Camas County line, the Camas Prairie deeper soil site is located. The site is in the highway right-of-way south of where the existing Route 20 intersects the old highway. Soils here are not rocky like those at stop #3. Instead, they are formed in deep alluvium. Heavy clay reduces water drainage, creating ephemerally flooded conditions. The soils here fit the Magic series and are classified as fine montmorillonitic, frigid, Entic Chromoxererts. This site is predominantly silver sagebrush, with scattered plants of early (*Artemisia longiloba*) and fuzzy sagebrush. Camas plants remain in fair abundance. The highway right-of-way is occasionally utilized by bands of sheep, but continues to support a diverse mixture of native plants, including a State sensitive species, Cusick's primrose (*Primula cusickiana*). This site may exemplify the floristic character of large portions of the Camas Prairie prior to Euroamerican settlement.

POSSIBLE EVOLUTION OF WOODY SAGEBRUSHES IN NORTH AMERICA

Scabland (*Artemisia rigida*) and early sagebrush occur in shallow, rocky basalt habitats similar to fuzzy sagebrush. Table 1 lists some of the endemic and disjunct plant species that occur at the Camas Prairie and other basalt subregions in Idaho (fig. 4) (Steele 1975). Many of these species occur only in Idaho, or are restricted to fuzzy sagebrush, scabland

Table 1—Endemic and disjunct plant species by basalt subregions within Idaho (fig. 4) (modified from Steele 1975)

| Species | Subregion | | |
	Brownlee	Camas	Owyhee
Artemisia papposa	—	X	X
Stylocline filaginea	—	X	X
Eriogonum thymoides	X	X	—
Ranunculus oresterus	X	X	—
Astragalus atratus			
var. *inseptus*	—	X	—
var. *owyheensis*	—	—	X
Primula cusickiana	—	X	—
Haplopappus insecticruris	—	X	—
Allium tolmiei var. *persimile*	X	—	—

sagebrush, or early sagebrush sites in the Western United States (see fig. 3) (Daubenmire 1982; McArthur and Plummer 1978). Some of these plants are found in two or all three of the different sagebrush habitats (table 2). There are geographic and climatic changes that influence the distribution of fuzzy, scabland, and early sagebrush species, although they share a preference for midelevation basalt parent material and shallow, ephemerally wet soils (fig. 3). Many of these unique distribution patterns are difficult to explain. Daubenmire (1982), commenting about scabland sagebrush, said, "Few plants of the Washington steppe present such a clearcut and interesting challenge for both autecology and historic geology."

I believe that climate, historic distribution, and individual physiological adaptations influence the distribution of these three sagebrush species. The factors influencing the distribution of many of the other plant species in table 1 remain a challenge. The Camas Prairie exhibits the greatest species diversity of the three basalt subregions in Idaho for these endemic and unique plants adapted to frigid basalt soils (table 1). This may indicate that many of these plants evolved in this area and have not dispersed widely.

One possible evolutionary pathway to the woody species of North American sagebrush is from the genus *Sphaeromeria*. This genus, discussed by Holmgren and others (1976), is common in the circumpolar and circumboreal floras. Other authors place some members of this genus within the genus *Tanacetum* (Hitchcock and Cronquist 1973). *Sphaeromeria* species are primarily herbaceous plants or subshrubs, but include at least one woody member, commonly known as chicken sage (*S. argentea* or *T. nuttallii*). Another member, cinquefoil tansy (*S. potentilloides*), occurs in the Camas Prairie in close geographic and ecological position to fuzzy sagebrush.

Fuzzy sagebrush is not considered in the subsection *Tridentatae* of the genus *Artemisia* because it has a pappus
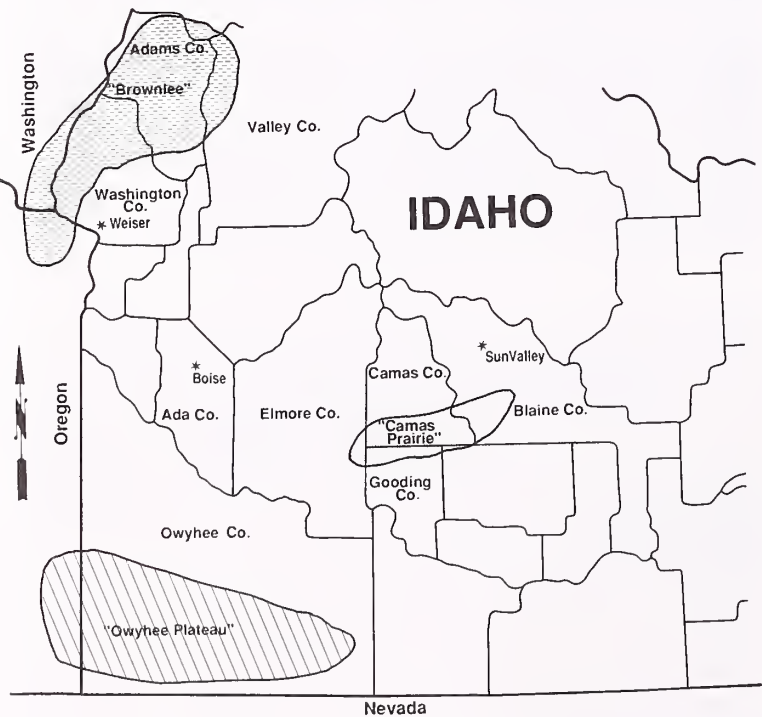
Table 2—Wide-ranging species with unusual geographic distribution patterns and occurring at similar ecological site

| Species | Subregion | | |
	Brownlee	Camas	Owyhee
Antennaria flagellaris	X	X	X
Artemisia longiloba	—	X	X
Trifolium microdon	X	X	X

(Hall 1923; McArthur and Plummer 1978; Shultz 1986; Ward 1953). The pappus is the same character that separates the genus *Sphaeromeria* from *Artemisia*. Therefore, it is possible that fuzzy sagebrush or a parental ancestor is the link between these two similar genera. In addition, the type of glandular hairs on the leaves of the two species are similar (Kelsey and others 1984), and their leaf shape and habitats are comparable. Their chemical makeup has not been investigated, but such work could help to elucidate evolutionary relationships (Kelsey and Shafizadeh 1979). Members of the genus *Sphaeromeria* may have been one of the parental taxa that migrated from the Old World (Asia) to evolve into the polyphyletic new world *Artemisia* subsection *Tridentatae* (Kelsey and Shafizadeh 1979).

ACKNOWLEDGMENTS

REFERENCES

Beetle, A. A. 1960. A study of sagebrush, the section *Tridentatae* of *Artemisia*. Bull. 368. Laramie, WY: University of Wyoming, Agricultural Experimental Station. 83 p.

Conley, C. 1982. Idaho for the curious. Cambridge, ID: Back Eddy Press. 532 p.

Daubenmire, R. 1982. The distribution of *Artemisia rigida* in Washington: a challenge to ecology and geology. Northwest Science. 3: 162-164.

Egan, R. S. 1987. A fifth checklist of the lichen-forming, lichenicolous and allied fungi of the continental United States and Canada. The Bryologist. 90(2): 77-173.

Hall, H. M.; Clements, F. E. 1923. The phylogenetic method in taxonomy, the North American species of *Artemisia, Chrysothamnus*, and *Atriplex*. Publ. 326. Washington, DC: Carnegie Institute. 355 p.

Hitchcock, C. L.; Cronquist, A. 1973. Flora of the Pacific Northwest. Seattle, WA: University of Washington Press. 730 p.

Holmgren, A. H.; Shultz, L. M.; Lowery, T. K. 1976. *Sphaeromeria*, a genus closer to *Artemisia* than to *Tanacetum* (Asteraceae: Anthemideae). Brittonia. 28: 255-262.

Kelsey, R. G.; Reynolds, G. W.; Rodriguez, E. 1984. The chemistry of biologically active constituents secreted and stored in plant glandular trichomes. In: Rodriguez, E.; Healey, P. L.; Mehta, I., eds. Biology and chemistry of plant trichomes. New York: Plenum Press: 187-241.

Figure 4—Basalt regions in southwestern Idaho with frigid soil temperatures.

Kelsey, R. G.; Shafizadeh, F. 1979. Sesquiterpene lactones and systematics of the genus *Artemisia*. Phytochemistry. 18: 1591-1611.

Maley, Terry. 1991. [Personal communication.] May 20, 1991. Bureau of Land Management, Idaho State Office, 3380 Americana Terrace, Boise, ID.

McArthur, E. D.; Plummer, A. P. 1978. Biogeography and management of native western shrubs: a case study, section *Tridentatae* of *Artemisia*. Great Basin Naturalist Memoirs. 2: 229-243.

McArthur, E. D.; Pope, C. L.; Freeman, K. C. 1981. Chromosomal studies of subgenus *Tridentatae* of *Artemisia*; evidence for autopolyploidy. American Journal of Botany. 68: 589-605.

Shultz, L. M. 1986. Taxonomic and geographic limits of *Artemisia* subgenus *Tridentatae* (Beetle) McArthur (Asteraceae: Anthemideae). In: McArthur, E. D.; Welch, B. L., compilers. Proceedings—symposium on the biology of *Artemisia* and *Chrysothamnus*; 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 20-28.

Steele, R. W. 1975. A directory to disjunct and endemic plants of central and southern Idaho. Information Series 9. Moscow, ID: University of Idaho, College of Forestry, Wildlife, Range Sciences. 26 p.

Quinney, Dana. 1991. [Personal communication]. May 21, 1991. Boise, ID.

Ward, G. H. 1953. *Artemisia*, section *Seriphidium*, in North America a cytotoxonomic study. Contributions from the Dudley Herbarium. 4(6): 155-205.

GRAZING-RIPARIAN ISSUES: A SAWTOOTH NATIONAL RECREATION AREA FIELD TRIP

Warren P. Clary
Nancy L. Shaw

ABSTRACT

The spectacular Sawtooth National Recreation Area (SNRA) was the site of an all-day, mid-meeting field trip. Special emphasis was given to the relationship between domestic livestock grazing and riparian-stream conditions through discussions at Horton/Pole Creeks and Stanley Creek. Stops at areas of general interest included the SNRA Headquarters, scenic Redfish Lake, and the Sawtooth salmon and steelhead fish hatchery. Field identification of local willow species offered opportunities for deliberation and dialog at nearly every stop.

INTRODUCTION

This field tour of the Sawtooth National Recreation Area (SNRA) provided symposium participants with an opportunity to see one of the most beautiful spots in western North America. Sawtooth Valley is a classic high-mountain valley. Three mountain ranges with a total of 40 peaks exceeding 10,000 feet in height enclose the valley and provide scenic landscapes in every direction. Hundreds of small streams and high-mountain lakes lie within these ranges. Headwater streams of the Salmon River converge below Galena Summit forming the legendary "River of No Return," which drains Sawtooth Valley.

The central portion of the valley supports a typical mountain meadow ecosystem. The growing season within the valley is short; snow covers the ground from November through April or May. Within the past year the minimum temperature reached a mere –46 °F. The mosaics of plant communities forming riparian complexes along the river include beaked sedge (*Carex rostrata*), willow (*Salix wolfii, S. planifolia, S. drummondiana, S. boothii, S. geyeriana*)/beaked sedge, Geyer willow/bluejoint reedgrass (*Calamagrostis canadensis*), Drummond willow (*S. drummondiana*)/bluejoint reedgrass, baltic rush (*Juncus balticus*), shrubby potentilla (*Potentilla fruticosa*)/timber oatgrass (*Danthonia intermedia*), and tufted hairgrass (*Deschampsia caespitosa*).

The SNRA was established by Congress in 1972. Exceptional scenic values of the Sawtooth area and the special wording of the establishment legislation present complex and sometimes conflicting management issues unusual in the National Forest System. Included within the establishment legislation was direction for Federal control of private land development to maintain a pastoral character within Sawtooth Valley and Stanley Basin. Domestic livestock grazing has been a continuous and characteristic activity within these two areas since the late 1880's. Mining of precious metals dates back to the mid-1880's, but filing of new claims was stopped by the establishment legislation. A major consideration of the legislation was to protect and conserve the salmon and other fisheries. Before settlement the Sawtooth Valley and Stanley Basin provided outstanding spawning habitats for chinook and sockeye salmon, steelhead, and four species of resident trout.

The location of the SNRA near the symposium's Sun Valley meeting site provided an excellent opportunity for participants to visit this Idaho showplace and to observe and discuss local management issues and grazing research.

THE FIELD TRIP

The day began with an early and therefore on-time loading of three tour buses. The first stop was at the Headquarters of the SNRA (fig. 1). The presentation by Art Selin on SNRA characterisics, history, and management was enhanced by a flight of Canada geese and intermittent breaks in the clouds allowing the sun to light the surrounding mountain peaks (fig. 2). Thereafter, the group was treated to discussions on willow identification and ecology lead by Howard Hudak and supplemented by Steve Brunsfeld (fig. 3). Hudak pointed out that high-gradient streams in the area usually support thinleaf alder (*Alnus incana*), black cottonwood (*P. trichocarpa*), and a few willows such as Booth willow or Drummond willow. For lower gradient streams there is likely to be a dominance of Geyer willow, Pacific willow (*Salix lasiandra*), yellow willow (*S. lutea*), or wolf willow (*S. wolfii*). Each person in the group can now, without hesitation, identify all of these species, plus Lemmon willow (*S. lemmonii*), sandbar willow (*S. exigua*) and many other Salicaceae!

The tour then proceeded over Galena Summit (8,701-foot elevation) to the second stop at Horton and Pole Creeks. Bert Webster lead a discussion of grazing history of the SNRA in general and the Horton Creek site in particular (fig. 4). At one time, perhaps 200,000 sheep grazed in what is now the SNRA. These sheep were moved
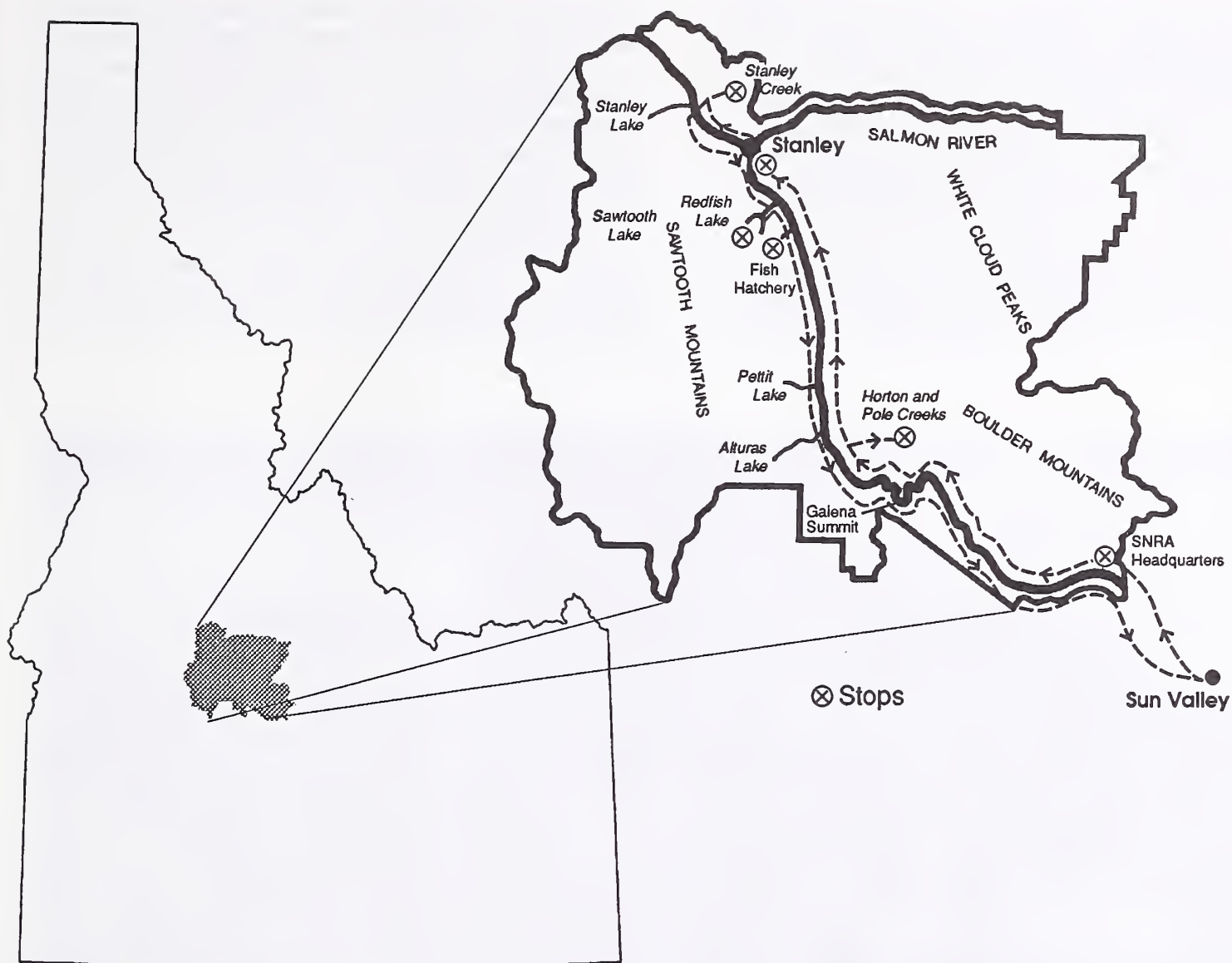
Figure 1—Location of the Sawtooth National Recreation Area and the field trip route.

Figure 2—Art Selin describes the SNRA characteristics, history, and management.

through the Horton Creek meadow up to four times each year during the period of peak livestock numbers. This excessive animal impact apparently had a major and persistent effect on this small stream (fig. 5). An adjacent Forest Service administrative site protected for more than 80 years provides a comparison to the heavily impacted meadow (fig. 6). The portion of Horton Creek impacted by livestock is now four times wider but only one-fifth as deep as the protected portion.

At the Horton Creek stop Susan Bernatas described the purposes of Research Natural Areas (RNA's) and discussed the RNA network in Idaho. The fenced administrative site at the Horton Creek/Pole Creek junction is a proposed Research Natural Area. This designation is being sought to protect a valuable reference area for the mountain meadow riparian-stream system and the adjacent mountain big sagebrush/Idaho fescue (*Artemisia tridentata* ssp. *vaseyana*/*Festuca idahoensis*) habitat type. Because of the old ranger's cabin, this area has also been listed on the National Register of Natural and Historic Places.

At the lunch stop along nearby Pole Creek the group viewed a fish screen at an irrigation withdrawal site. There are over 20 fish screens in operation on the SNRA.

Figure 3—Howard Hudak demonstrates how to identify certain willows and explains where they can be found.

Figure 4—Tour participants listen to Bert Webster recount the management history of the SNRA.

Their purpose is to protect out-migrating salmon and steelhead smolts by preventing them from being diverted onto irrigated hay fields. A fenced riparian demonstration area at the same location was described by Howard Hudak. One and three-fourths miles of Pole Creek has been fenced to protect the area from livestock grazing until the riparian area recovers. This project, conducted on private land under the scenic easement program of the SNRA, was funded by the Bonneville Power Administration and the landowner, Frank Henslee.

After lunch it was off to Stanley Creek, 5 miles north of the village of Stanley, ID. En route, the group viewed a segment of the Salmon River that had, until recently, been grazed season-long on the east side while the west side has been protected from livestock grazing for a number of years. The east bank no longer supports woody riparian plants. However, stands of willow and alder are present on the protected west bank.

At Stanley Creek Bert Webster described management conflicts that have arisen in regard to livestock grazing in the SNRA. Concerns expressed by recreation and fisheries interests as well as the Idaho Transportation Department have created a climate that may necessitate modification of livestock grazing practices within Stanley

Figure 5—Horton Creek has become wide and shallow from the impact of excessive sheep grazing.

Figure 6—The portion of Horton Creek protected from grazing is one-fourth as wide and five times deeper than the grazed portion.

Basin. In response to some of these grazing concerns the Intermountain Research Station and the Sawtooth National Forest developed a riparian grazing study along Stanley Creek in 1987. Experimental treatments include: (1) heavy meadow grazing, (2) light to medium meadow grazing, and (3) no grazing. Treatments are applied to replicated fenced pastures. Responses being evaluated include plant community structure and growth, populations of breeding birds and small mammals, and streambank conditions. Warren Clary explained that initial results show that timing of grazing in these meadows is very important. The cattle prefer to graze areas of drier soil, therefore they tend to avoid streambanks in June or very early July—an action which mimimizes streamside trampling impacts.

To round out the tour there was a stop providing a view across glacier-created Redfish Lake to the Sawtooth Mountains beyond, perhaps the most frequently photographed panorama in Idaho, and a tour of the nearby Sawtooth Fish Hatchery operated by the Idaho Department of Fish and Game. Redfish Lake was socked-in with heavy clouds, but hatchery personnel provided an enthusiastic description of their efforts to reestablish anadromous fish runs decimated by construction of dams on the lower Snake and Columbia Rivers.

After braving a spring snowstorm on Galena Summit, the group returned safely to Sun Valley and an informal get-together.

Includes 41 papers and accounts of field trips from a symposium focused on riparian
shrub communities and their habitats. Papers discuss values, classification methods,
conditions, and rehabilitation techniques for riparian areas, with one section devoted to
similar topics for upland shrubs.

KEYWORDS: succession, habitat types, community types, xeroriparian, species selection,
seed technology, cuttings, stress, plant yields, fire effects

Printed on recycled paper

INTERMOUNTAIN RESEARCH STATION
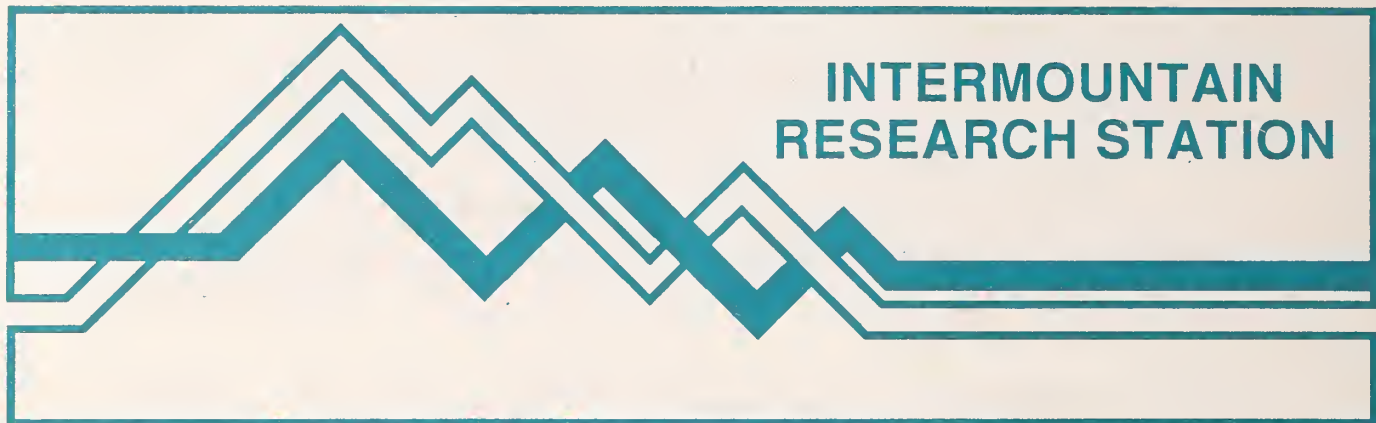
The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)